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# FINAL REPORT

December 28, 1968

## COMMUNICATIONS AND TRACKING RELAY EXPERIMENT STUDY PROGRAM

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## FINAL REPORT

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December 28, 1968

### COMMUNICATIONS AND TRACKING RELAY EXPERIMENT STUDY PROGRAM

#### PREPARED FOR

NASA  
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## SECTION I

### 1. INTRODUCTION

#### 1.1 EXPERIMENT PURPOSE

The NASA Communications and Tracking (CAT) Relay Experiment is designed to provide an operational duplex communication and tracking data relay between an orbiting Apollo Applications spacecraft and established ground stations via a geostationary satellite repeater. This experiment will make extensive use of proven flight equipment, existing ground stations and the Applications Technology Satellite (ATS) "F" spacecraft as a signal relay.

The major objectives of the CAT Relay Experiment are to demonstrate the following spacecraft technological capabilities:

1. Synchronous altitude data relay ability to supplant the mobile and certain fixed stations of the MSFN.
2. Adequacy of the data relay to provide simplex transmission of commercial quality television signals from the spacecraft.
3. Ability of a data relay system to maintain continuous ground contact with low altitude orbiting vehicles, regardless of their spatial location.
4. Enhancement of spacecraft communications during critical mission phases such as abort maneuvers, high inclination orbits, and recovery operations.

The success and experience derived from this Experiment is expected to establish a sound basis for more complex data relay satellite systems of the future. In fact, a properly instrumented network of synchronous relay satellites and support stations could provide complete data acquisition and orbit tracking for a wide range of simultaneous missions (manned and unmanned space research and applications vehicles) with significantly increased capabilities and potentially fewer ground stations than presently practical.

#### 1.2 PROGRAM SCOPE

The objective of the Communications and Tracking Relay Experiment Study program is to define a system using the ATS-F as a duplex relay

between a low orbiting Apollo Applications spacecraft and the Mojave Ground Station. The program is to include a feasibility demonstration of the CAT Relay System design, identification of the requirements for all three terminals required for the Experiment, analysis of the operating data transmission modes and the tracking and acquisition procedures.

The data transmission modes to be analyzed include duplex voice, telemetry and ranging and simplex downlink monochrome television transmission. The major focus of the program is to be directed to the evaluation of trade-offs in the television relay link in order to provide detailed definition of the requirements for this link. The feasibility demonstration is to consist of a laboratory simulation of the television/voice mode of operation. The specification and installation of the CAT Relay equipment in the Apollo Applications spacecraft is also to be given significant attention.

The experimental nature of the final system operation is to be kept in mind throughout the design in order to arrive at a reasonable compromise between economy and probable mission success.

### 1.3 PROGRAM RESULTS

Motorola has designed a versatile Communications and Tracking Relay System with a variety of data relay capabilities. The more important features of the recommended basic CAT Relay System are:

- The majority of the flight equipment traces to space qualified designs including an all solid state 11 watt transmitter.
- A fine quality television transmission downlink using wideband FM deviation and including a simultaneous high quality voice link.
- Ranging turnaround versatility for Mark I or ATSR systems with high instrumental accuracy.
- Duplex USBE telemetry and voice transmission capability.
- Deployable 10 foot antenna on the orbiting spacecraft which can open-loop track the ATS-F.
- Duplex back-up voice transmission for any spacecraft attitude using omni-antennas.
- Configuration versatility which allows addition of link services or increased link margins with minor impact on the basic system.

- Estimated flight equipment weight of 238 pounds and 177 watts prime power consumption.
- Easy conversion of the downlink system for color television transmission.
- Sufficient television link margin to obtain useable video after significant unforeseen link degradation.

Motorola has successfully demonstrated a laboratory simulation of the television/voice downlink mode including color transmission. Detailed link analyses have been completed which show the recommended system has 0.9 db margin for simultaneous worst case parameters. A conceptual installation plan has been developed which locates the flight equipment most advantageously aboard the Apollo Applications Cluster workshop. Details of the flight equipment portion of the recommended basic system have been completed including preliminary component specifications. Definition of the ATS-F and ATS Ground Station performance requirements is also complete.

#### 1.4 REPORT OUTLINE

This final report details the system design and analysis, laboratory testing, and the recommended basic CAT Relay system design which was performed by Motorola during the CAT Relay Experiment Study Program. The report begins with a summary of the Experiment fundamentals (Section 2) which were assumed, calculated and NASA defined. Based upon these fundamentals, the system design analysis and laboratory simulation test results are presented. The basic CAT Relay System recommendations (Section 6) are then determined and detailed from the analysis, test results and equipment tradeoff studies. The available alternatives to the basic System design are defined, the metric tracking accuracy analysis presented and the laboratory demonstrations summarized to complete the report and the identification of the tasks performed on this study contract.

## SECTION II

### 2. EXPERIMENT FUNDAMENTALS

#### 2.1 TERMINAL DESCRIPTION

The principle terminals selected for the present CAT Relay Experiment design are (1) the Mojave Applications Technology Satellite (ATS) Ground station, (2) the ATS-F Satellite, and (3) an Apollo Applications Cluster (AAC) spacecraft. The ATS-F spacecraft provides simultaneous crossband frequency translation and relay of the ground-to-Cluster and Cluster-to-ground signals. The Mojave Station will always be within sight of the ATS-F and has been designated by NASA to be customized as necessary for the CAT Relay Experiment. An overland communication link from Mojave to the nearby Goldstone MSFN station will be provided for the USBE baseband format generation and detection capability for the experiment. The Apollo Mission Control Center at Houston (MCC-H) will be connected to these ground stations via the MSFN. The AAC spacecraft can be either the Saturn IVB Workshop or the backup Workshop spacecraft. The Experiment concept as described herein is also applicable to the Saturn V Workshop.

These principle terminals are shown in foreshortened proximity in Figure 2-1. The major characteristics of these terminals are indicated in Figure 2-1, however, significantly more detail on the capability and equipment at each terminal is given elsewhere throughout this report. The 10 foot parabolic reflector on the AAC is not part of the basic AAC equipment but has been added in order to perform the CAT Relay Experiment.

#### 2.2 SPATIAL RELATIONSHIPS

A 265-mile circular AAC orbit at 28.9 degrees inclination has been defined as the AAC orbit<sup>2.1</sup> for the basis of the Relay Experiment design. During Relay Experiment exercises, the AAC is assumed to be positioned with the CSM toward the north, the solar panels always sun-oriented, and the Cluster at right angles to the orbital plane. The ATS-F will be positioned in geostationary orbit and is expected to be within simultaneous antenna view of both Rosman and Mojave ATS Stations. This bounds the probable ATS-F location to between 50°W and 148°W which are used as the assumed ATS-F locations throughout the remainder of this report. The ATS-F X-band antenna is assumed to remain fixed on the equator while the ATS-F 30-foot, electro-mechanically-steered, S-band antenna is ground commanded to track the AAC orbit. Concurrently, the antenna aboard the AAC will be ground commanded to track the ATS-F.

**GOLDSTONE**  
**MSFN STATION**  
USBE FORMAT  
GENERATION/  
DETECTION

**MISSION CONTROL**  
**CENTER-HOUSTON**  
VOICE,  
COMMAND  
GENERATION

**MOJAVE**  
**ATS STATION**  
40 FOOT REFLECTOR  
ATSR GENERATION/DETECTION  
VOICE, TV VIDEO DETECTION

**ATS-F**  
GEOSTATIONARY ORBIT  
30 FOOT REFLECTOR (S-BAND)  
20° X-BAND HORN  
CROSSBAND SIGNAL RELAY

# CAT RELAY TERMINALS

**AAP CLUSTER**  
265 MILE ORBIT  
28.9° INCLINATION  
10 FOOT REFLECTOR  
CREW VOICE, TV VIDEO  
GENERATION

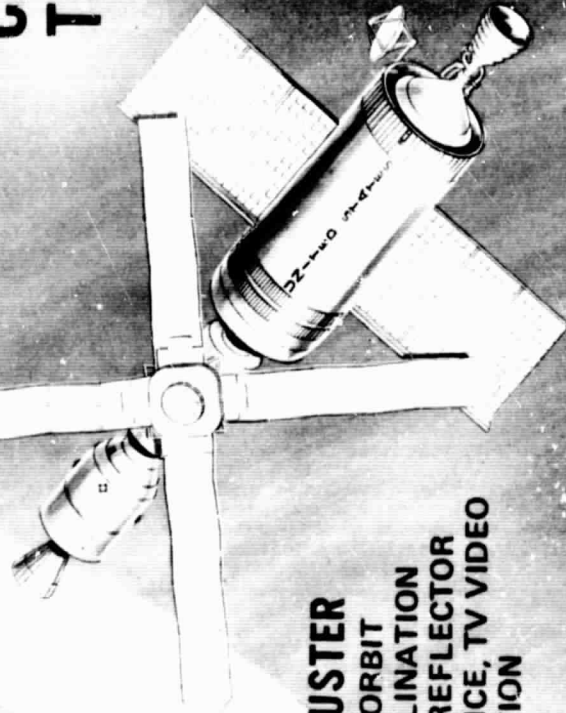


Figure 2-1. CAT Relay Terminals

The resulting spatial relationships of the principal terminals is shown by Figure 2-2. The S-band tracking capability of the ATS-F is restricted to a 15 degree cone by the present ATS-F specification<sup>2.2</sup> as shown in Figure 2-2. The X-band link uses a 20° conical beamwidth antenna for ground to ATS-F communication which covers the entire earth without ATS-F beam steering as shown. If the common plane that includes the ATS-F and the AAC orbit is examined as in Figure 2-3, the geometry and AAC range extremes can be demonstrated. These relationships are also shown in Figure 2-4 as visibility contours along with visibility contours from some of the MSFN Stations.

It should be pointed out that the restricted 15° visibility cone is peculiar to the ATS-F beam steering restraints. The CAT Relay System is operable over the virtual horizon cone of coverage if adequate link margins are available. A different synchronous relay satellite such as a phased array data relay could possibly provide relay capability to obtain beam steering to the virtual horizon.

### 2.3 AAC ORBIT DYNAMICS

The relative path dynamics between the Cluster and ATS-F were computed considering the ATS-F to be geostationary and the orbit of the AAC as 426 km altitude circular with 28.9 degrees inclination. The AAC period for this orbit is 93.1 minutes and the AAC attitude was assumed to always be sun oriented. Table 2-1 is a printout of an orbit yielding some of the highest dynamics and includes data inside a 18.5° ATS-F visibility cone. After considering all possible orbits, the maximum orbit dynamics as summarized in Table 2-2 have been determined and utilized for the CAT Relay design.

The ATS-F to Mojave Ground Station link has no orbital dynamics because the ATS-F is geostationary and the X-band antenna is assumed to always be boresighted on the equator. The variation in range parameters with ATS-F location is listed in Table 2-3.

### 2.4 OPERATING MODES

The CAT Relay uplink signal transmission services and frequencies are shown in Figure 2-5 and the downlink services in Figure 2-6. Additionally uplink and downlink Back-Up Voice modes using omni-antennas and carrier PM transmission is available. The ATS-F/ATS Ground Station frequencies are tentative assignments. The coherent AAC/ATS-F links will operate at approximately SGLS channel 10 (1800/2247.8 MHz) with phase modulated carriers and the standard SGLS 256/205 turn-around frequency ratio. Since the lower frequency uplink is specified<sup>2.2</sup> as 1800.0 MHz  $\pm$ 100 Hz, the nominal downlink frequency will therefore be defined as 2247.8049 MHz.

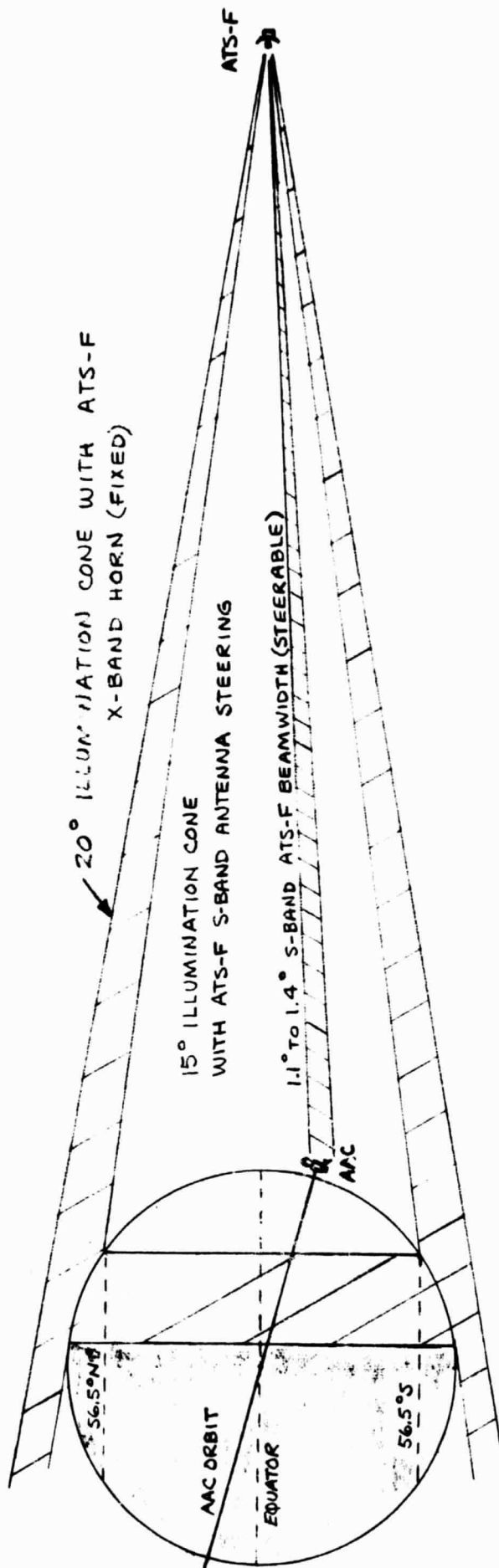


Figure 2-2. ATS-F Antenna Illumination

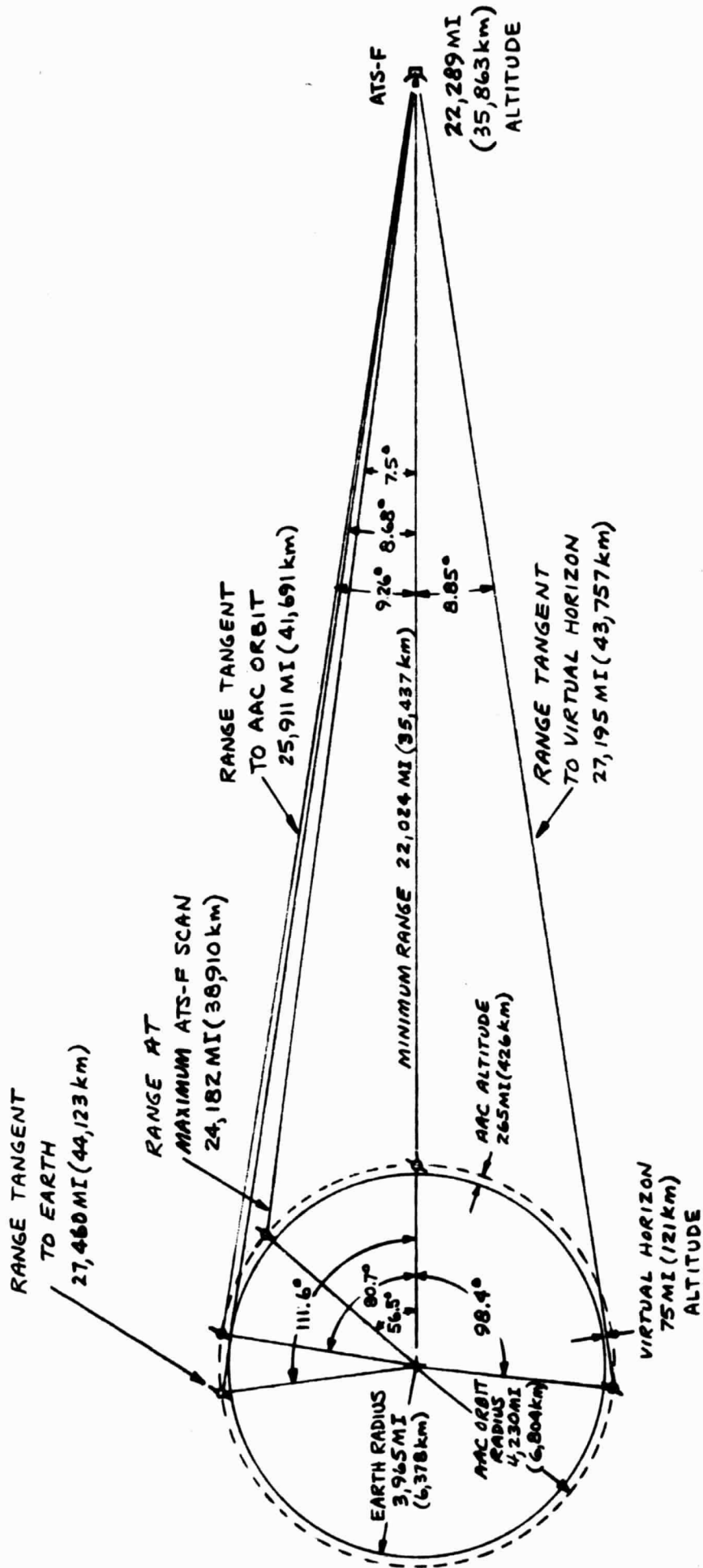


Figure 2-3. Orbital Geometry

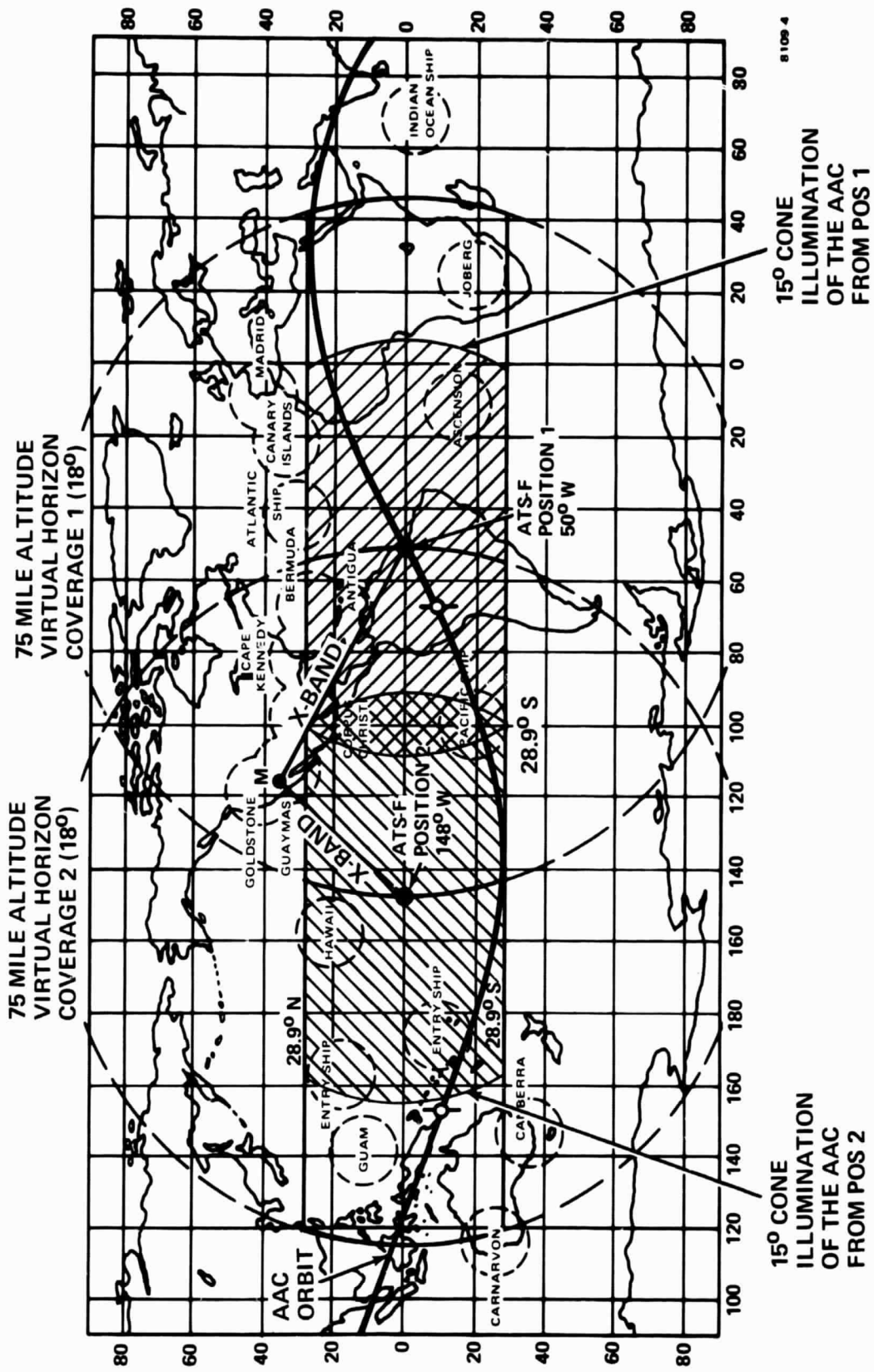


Figure 2-4. S-Band Visibility Contours From the ATS-F

TABLE 2-1. TYPICAL AAC ORBITAL DYNAMICS

TIME [SEC]	RANGE [METERS]	VEL [M/S]	DV/DT	[M/S/S]	AZ [DEG]	EL [DEG]
6.40500E 04	43827147.152	-6869.546		-2.251	175.370	4.212
6.41000E 04	43480997.668	-6973.587		-1.909	175.050	4.289
6.41500E 04	43130078.423	-7060.229		-1.555	174.750	4.354
6.42000E 04	42775275.319	-7128.837		-1.188	174.470	4.406
6.42500E 04	42417505.612	-7178.791		-.809	174.210	4.445
6.43000E 04	42057717.106	-7209.491		-.418	173.971	4.471
6.43500E 04	41696887.068	-7220.359		-.015	173.754	4.484
6.44000E 04	41336020.936	-7210.846		.398	173.559	4.482
6.44500E 04	40976150.714	-7180.440		.820	173.388	4.466
6.45000E 04	40618333.074	-7128.668		1.252	173.239	4.435
6.45500E 04	40263647.114	-7055.107		1.692	173.114	4.388
6.46000E 04	39913191.694	-6959.390		2.138	173.014	4.327
6.46500E 04	39568082.421	-6841.217		2.590	172.938	4.250
6.47000E 04	39229448.139	-6700.360		3.045	172.887	4.158
6.47500E 04	38898426.963	-6536.676		3.502	172.861	4.049
6.48000E 04	38576161.853	-6350.117		3.960	172.860	3.925
6.48500E 04	38263795.651	-6140.738		4.415	172.883	3.786
6.49000E 04	37962465.622	-5908.708		4.865	172.931	3.631
6.49500E 04	37673297.534	-5654.320		5.309	173.003	3.461
6.50000E 04	37397399.216	-5378.000		5.742	173.099	3.276
6.50500E 04	37135853.722	-5080.314		6.163	173.219	3.077
6.51000E 04	36889712.106	-4761.977		6.568	173.360	2.864
6.51500E 04	36659985.880	-4423.856		6.954	173.523	2.638
6.52000E 04	36447639.276	-4066.975		7.318	173.706	2.399
6.52500E 04	36253581.392	-3692.517		7.656	173.907	2.149
6.53000E 04	36078658.371	-3301.817		7.967	174.127	1.889
6.53500E 04	35923645.724	-2896.362		8.246	174.362	1.619
6.54000E 04	35789240.975	-2477.784		8.491	174.612	1.341
6.54500E 04	35676056.777	-2047.844		8.700	174.874	1.056
6.55000E 04	35584614.625	-1608.424		8.870	175.147	.765
6.55500E 04	35515339.375	-1161.506		9.000	175.428	.471
6.56000E 04	35468554.633	-709.154		9.087	175.715	.173
6.56500E 04	35444479.201	-253.491		9.132	176.007	-.126
6.57000E 04	35443224.631	203.319		9.133	176.300	-.424
6.57500E 04	35464793.969	659.103		9.091	176.593	-.721
6.58000E 04	35509081.727	1111.697		9.006	176.884	-1.015
6.58500E 04	35575875.076	1558.976		8.879	177.170	-1.303
6.59000E 04	35664856.235	1998.871		8.711	177.448	-1.586

APPROXIMATE  
15° ATS-F  
CONICAL  
COVERAGE

TABLE 2-1. TYPICAL AAC ORBITAL DYNAMICS (CONT'D)

TIME (SEC)	RANGE (METERS)	VEL (M/S)	DV/DT (M/S/S)	AZ (DEG)	EL (DEG)
6.59500E 04	35775605.931	2429.396	8.504	177.718	-1.861
6.60000E 04	35907608.197	2848.665	8.261	177.977	-2.127
6.60500E 04	36060255.335	3254.909	7.983	178.223	-2.384
6.61000E 04	36232854.656	3646.491	7.675	178.454	-2.629
6.61500E 04	36424635.101	4021.917	7.338	178.669	-2.862
6.62000E 04	36634754.631	4379.843	6.975	178.865	-3.082
6.62500E 04	36862307.890	4719.082	6.591	179.043	-3.289
6.63000E 04	37106334.049	5038.601	6.187	179.200	-3.481
6.63500E 04	37365824.645	5337.526	5.768	179.336	-3.658
6.64000E 04	37639731.354	5615.138	5.335	179.449	-3.820
6.64500E 04	37926973.551	5870.862	4.893	179.539	-3.966
6.65000E 04	38226445.541	6104.269	4.443	179.606	-4.096
6.65500E 04	38537023.457	6315.060	3.988	179.648	-4.210
6.66000E 04	38857571.695	6503.063	3.532	179.666	-4.308
6.66500E 04	39186948.835	6668.218	3.075	179.660	-4.390
6.67000E 04	39524013.387	6810.571	2.620	179.628	-4.456
6.67500E 04	39867628.254	6930.263	2.169	179.572	-4.506
6.68000E 04	40216665.718	7027.519	1.723	179.492	-4.540
6.68500E 04	40570011.163	7102.638	1.283	179.387	-4.559
6.69000E 04	40926566.656	7155.987	.852	179.258	-4.563
6.69500E 04	41285254.009	7187.987	.430	179.106	-4.552
6.70000E 04	41645017.425	7199.112	.017	178.931	-4.527
6.70500E 04	42004825.790	7189.874	-.385	178.732	-4.488
6.71000E 04	42363674.567	7160.822	-.775	178.512	-4.436
6.71500E 04	42720587.407	7112.535	-1.154	178.271	-4.371
6.72000E 04	43074617.482	7045.613	-1.521	178.008	-4.294
6.72500E 04	43424848.524	6960.678	-1.875	177.726	-4.205
6.73000E 04	43770395.683	6858.365	-2.216	177.423	-4.104
6.73500E 04	44110406.192	6739.321	-2.544	177.102	-3.993

APPROXIMATE  
15° ATS-F  
CONICAL  
COVERAGE

Obviously all services cannot be used simultaneously, so the operating modes given in Table 2-4 have been selected for the Experiment. Downlink services are restricted to either PM or FM carrier modulation and are not available simultaneously. Operating mode requirements for services identical to the USBS are identically defined.

Table 2-2. Orbit Dynamics ATS-F to AAC S-Band Link

Parameter	18.5° Conical Coverage	15° Conical Coverage
AAC Period	93.1 minutes	
Range		
Maximum	27,460 mi (44,123 km) <sup>†</sup>	24,182 mi (38,910 km)
Minimum	22,024 mi (35,437 km)	22,024 mi (35,437 km)
Variation in Path Loss	1.9 db	0.8 db
Maximum Velocity	+7220 meters/sec	+6560 meters/sec
Maximum Acceleration	9.142 meters/sec/sec	9.142 meters/sec/sec
Maximum Doppler		
2250 MHz	+54.1 kHz	+49.2 kHz
1800 MHz	+43.4 kHz	+39.4 kHz
Maximum Doppler Rate		
2250 MHz	68.5 Hz/sec	68.5 Hz/sec
1800 MHz	55.0 Hz/sec	55.0 Hz/sec
Tracking Angles*		
Azimuth		
Total Control Required	360°	360°
Maximum Control per Pass	8.9°	8.7°

Table 2-2. Orbit Dynamics ATS-F to AAC S-Band Link (cont)

Parameter	18.5° Conical Coverage	15° Conical Coverage
Maximum AAC Slew Rate	0.006°/sec	0.006°/sec
Elevation		
Total Control Required	±5.2°	±5.2°
Maximum Control per Pass	9.1°	8.4°
Maximum AAC Slew Rate	0.006°/sec	0.006°/sec
AAC Orbit Visibility	54.5% <sup>+</sup>	31.4%
	51 minutes	29.2 minutes

<sup>+</sup> At 17.4° cone intercept with the far orbit (tangent to earth horizon).

\* Assumes AAC is fixed on the sun, and r-f contact with ATS-F on every pass of the AAC.

Table 2-3. ATS-F to Mojave Ground Station Range X-Band Link

	50°W	117°W	148°W
Geostationary Longitude (Antenna Boresight)	50°W	117°W	148°W
Nominal Range			
Statute Miles	25,584	23,132	23,784
Kilometers	41,165	37,220	38,269
Variation in Path Loss	+0.9 db	0	+0.2 db
Pointing Angle	8.62°	5.68°	7.11°
20° X-Band Antenna Pointing Loss			
Assuming Equatorial Boresight	2.23 db	0.97 db	1.52 db

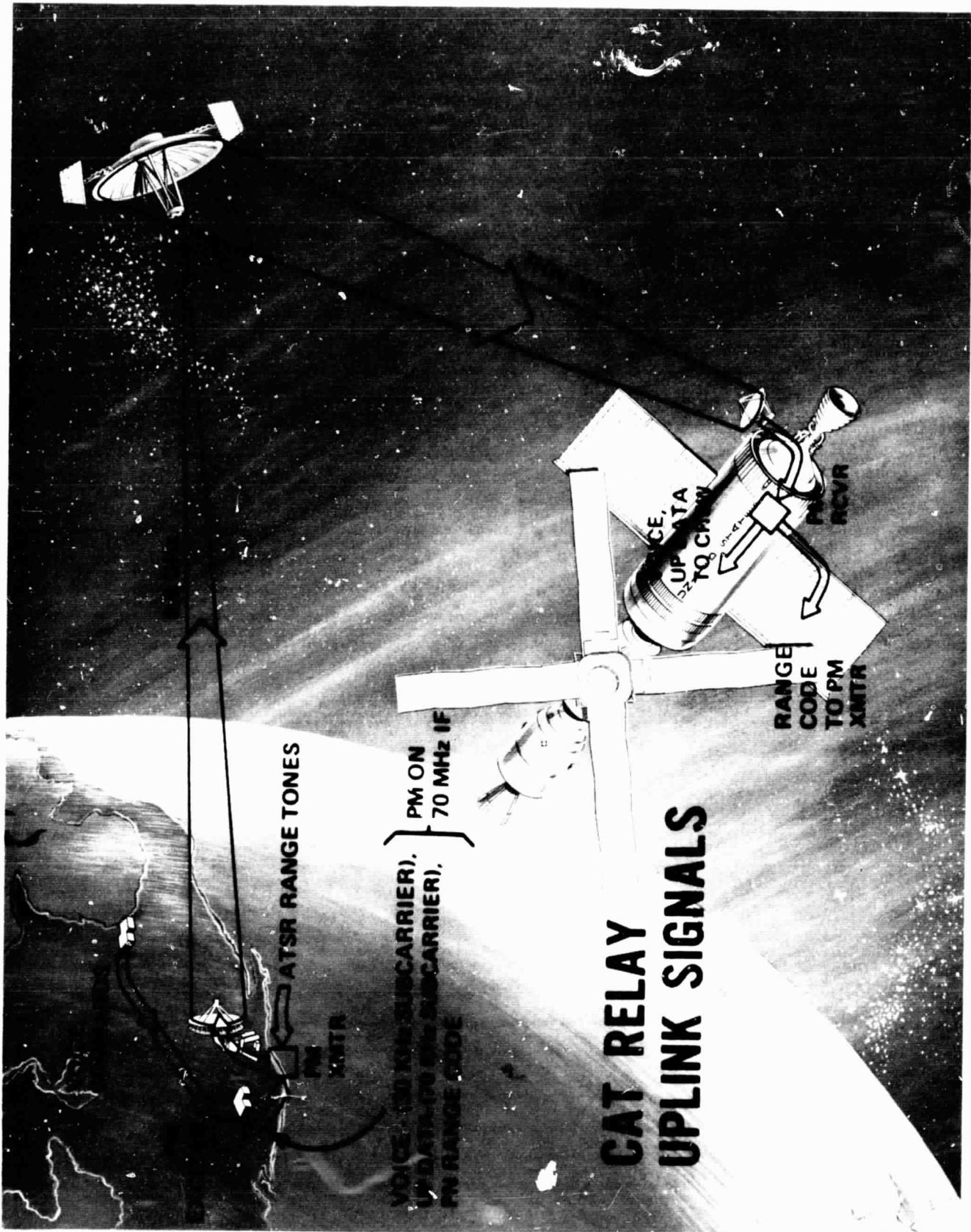


Figure 2-5. CAT Relay Uplink Signals Using Steerable Antenna

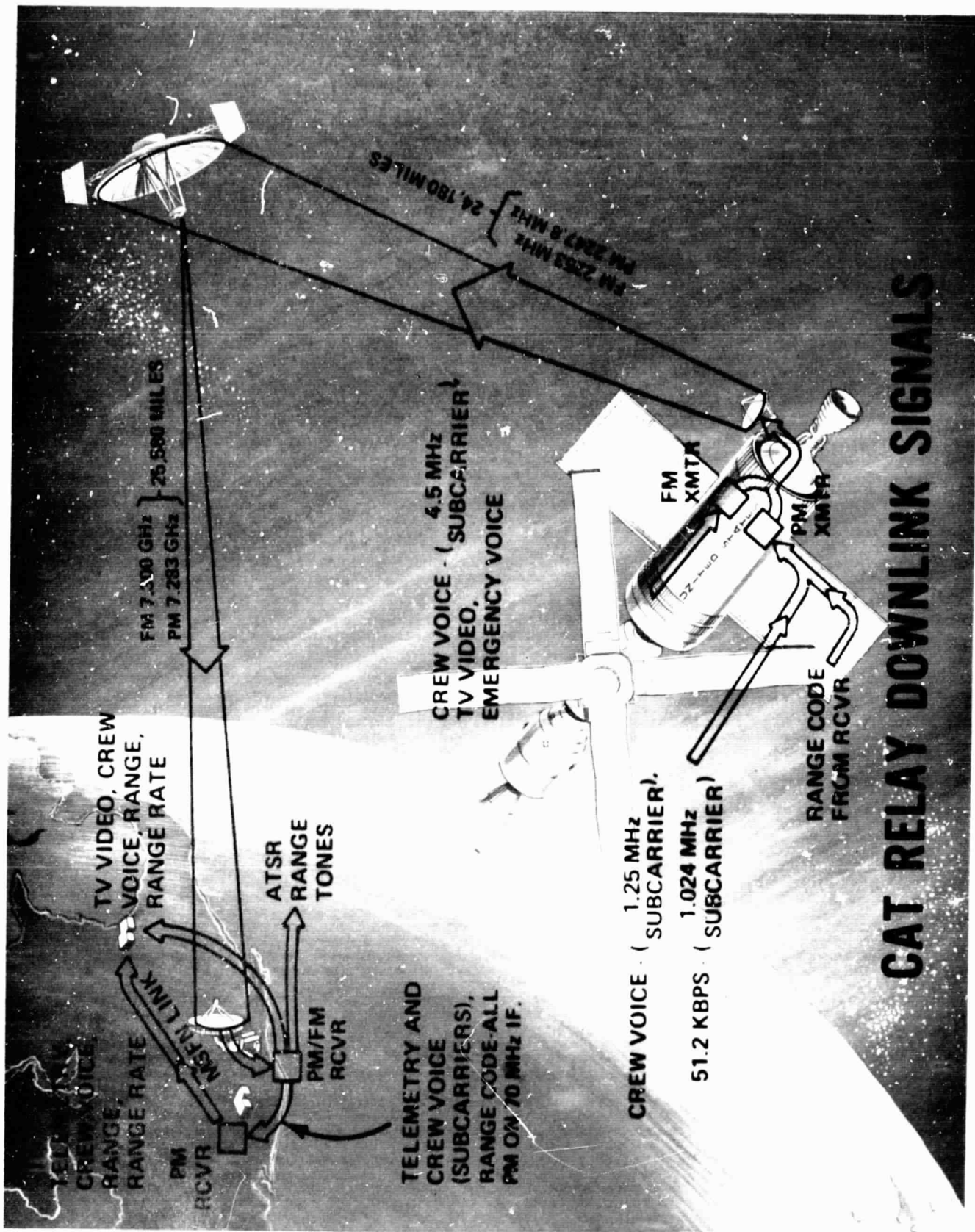


Figure 2-5. CAT Relay Downlink Signals Using Steerable Antenna

Table 2-4. CAT Relay Operating Modes

Mode	Information	Modulation Technique	Subcarrier Frequency	Peak Carrier Deviation	Antenna Steerable Omni
Up Mode 1	Carrier	- - -	- - -	0	x x
Up Mode 2	PRN Ranging	PM	- - -	1.34 radians	x
Up Mode 3	Voice	FM/PM	30 kHz	1.85 radians	x
Up Mode 4	Up-Data	FM/PM	70 kHz	1.85 radians	x
Up Mode 5	Voice Up-Data	FM/PM FM/PM	30 kHz 70 kHz	1.1 radians 1.1 radians	x
Up Mode 6	Voice Up-Data PRN Ranging	FM/PM FM/PM PM	30 kHz 70 kHz - - -	1.0 radian 0.76 radian 0.5 radian	x
Up Mode 7	ATS-R 5 MHz Tracking Mode (ATS-R Mode 2)	PM	4 kHz to 5 MHz tones*	Maximum of 2 tones at 1.2 radians each	x
Up Mode 8	ATS-R 500 kHz Tracking Mode (ATS-R Mode 3)	PM	4 kHz to 500 kHz tones*	Maximum of 2 tones at 1.2 radians each	x
Up Mode 9 <sup>+</sup>	Back-Up Voice	PM	- - -	1.2 radians	x

Table 2-4. CAT Relay Operating Modes (cont)

Mode	Information	Modulation Technique	Subcarrier Frequency	Peak Carrier Deviation	Antenna Steerable Omni
Down PM Mode 1	Carrier	- - -	- - -	0	x x
Down PM Mode 2	PRN Ranging	PM	- - -	1.34 radians	x
Down PM Mode 3	Crew Voice TLM Data	FM/PM PM/PM	1.25 MHz 1.024 MHz	0.7 radian 1.2 radians	x
Down PM Mode 4	Crew Voice TLM Data PRN Ranging	FM/PM PM/PM PM	1.25 MHz 1.024 MHz - - -	0.7 radian 1.2 radians 0.5 radian	x
Down PM Mode 5	ATS-R 5MHz Tracking Mode	PM	4 kHz to 5 MHz Tones	Maximum of 2 tones at 1.2 radians each	x
Down PM Mode 6	ATS-R 500 kHz Tracking Mode	PM	4 kHz to 500 kHz tones	Maximum of 2 tones at 1.2 radians each	x
Down PM Mode 7	Back-Up Crew Voice	PM	- - -	1.2 radians	x
Down FM Mode 1 (No Pre-Emphasis)	TV Video Crew Voice	FM FM/FM	- - - 4.5 MHz	9.0 MHz 0.90 MHz	x

Table 2-4. CAT Relay Operating Modes (cont)

Mode	Information	Modulation Technique	Subcarrier Frequency	Carrier Deviation	Antenna Steerable Omni
Down FM Mode 2 (Video Pre-Emphasis)	TV Video Crew Voice	FM FM/FM	- - - 4.5 MHz	3.92 MHz RMS 0.90 MHz pk	x

\*See ATSR Design Evaluation Report, R-65-013, General Dynamics, pp 2-11, 2-12, 3-12, 3-26 for more details.

†Design goal. Basic CAT Relay System (Section 6) does not have this capability.

## REFERENCES

- 2.1 Cluster Systems Description Document, Volume I - General Cluster Data, MSFC, July 1968.
- 2.2 ATS-F Spacecraft Performance Requirements Specification for the Nimbus/AAP Data Relay Experiment, GSFC S-733-p-15, August 1968.

## SECTION III

### 3. SYSTEM DESIGN

With the establishment of the Experiment requirements in Section 2, the CAT Relay System downlink and uplink r-f transmission path details can be estimated and the USBE format mode performance examined using the estimated links. The television/voice FM link design is discussed first since it constrains much of the required CAT Relay equipment.

#### 3.1 TELEVISION/VOICE DOWNLINK MODE

Down FM Mode 1 operation requires the transmission of commercial TV<sup>3.1</sup> (Figure 3-1 format) from the AAC to the ATS ground station using the ATS-F as a radio relay repeater. From the ATS ground station, the demodulated video will probably have nationwide distribution over national television transmission networks or be recorded on video tape for later distribution. The television transmission must be accomplished without using excessive AAC r-f power and by using existing equipment designs wherever possible. As a final result of the transmission, the video image must be of reasonably good quality.

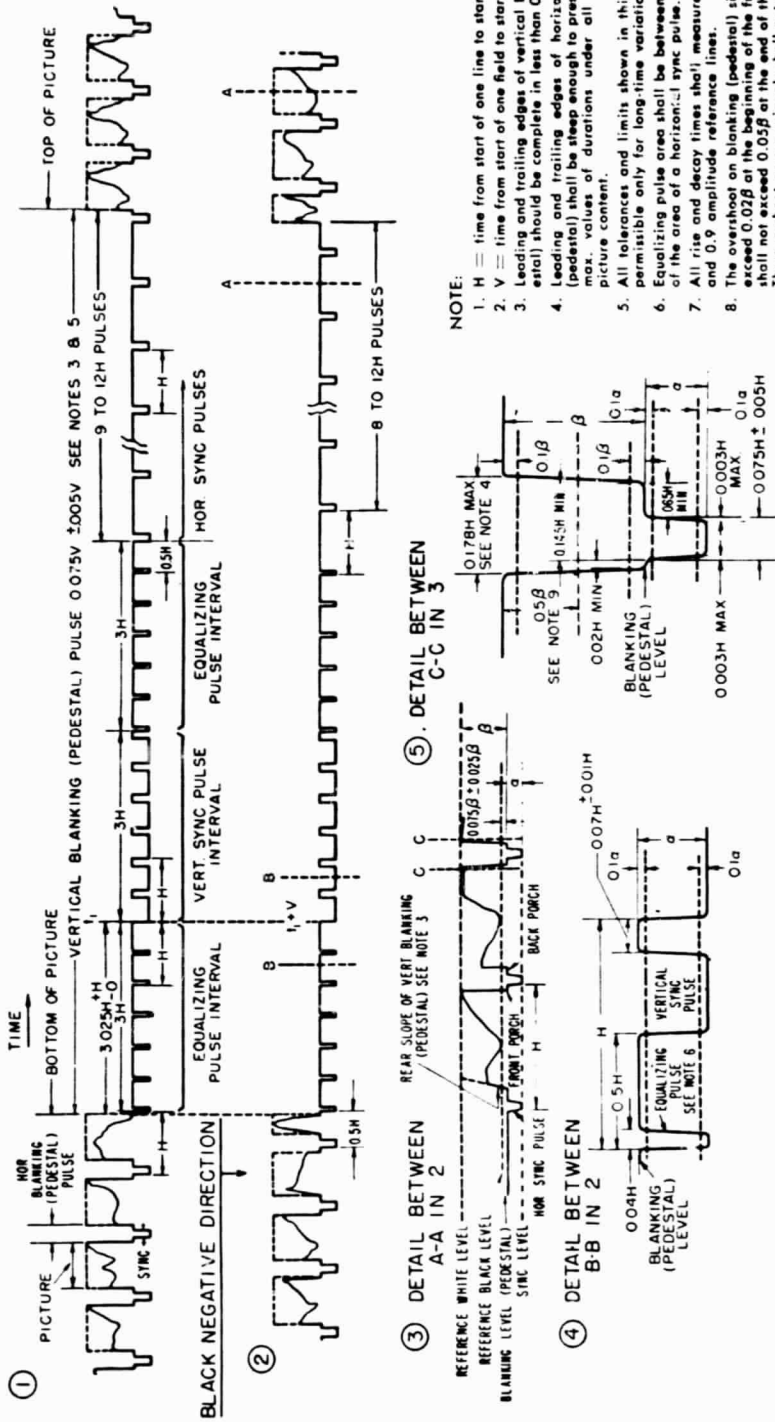
Two identical television systems are planned aboard the AAC which will provide video signals for the experimental relay to the ground. These are the AAP Cluster TV System and the Apollo Telescope Mount (ATM) closed circuit television system. Both systems are assumed to conform to Figure 3-1 in format.

##### 3.1.1 TV Transmission Requirements

Angle modulation becomes a logical choice for the modulation format upon consideration of some system constraints. The most salient reasons for the choice of angle modulation are the non-linear power amplifiers and the transmitter power limitations. Consideration was given to the possible use of phase modulation, frequency modulation, or some combination (pre-emphasized FM). The PM approach was discarded because available PM coherent detectors are limited to about  $\pm 1.5$  radians peak deviation which limits the strong signal improvement possible. Also, the phase lock loop detector does not permit low frequency modulation -- a must for commercial TV. The choice then becomes one of using either FM with or without pre-emphasis. In considering the character of the noise density near the expected above threshold operating point and the desired SNR versus frequency, there is no significant advantage in the use of

**MONOCHROME TELEVISION  
PICTURE LINE AMPLIFIER STANDARD OUTPUT** (VISUAL TRANSMITTER INPUT SIGNAL WAVEFORM)

SYNC SIGNAL AMPLITUDE  $a$  SHALL BE HELD CONSTANT WITHIN  
- 4% DURING TRANSMISSION  
 $B = 1.0 \pm 0.05$  VOLTS  
 $a = 0.4B \pm 0.05B$   
DRAWINGS NOT TO SCALE



- NOTE:
1. H = time from start of one line to start of next line.
  2. V = time from start of one field to start of next field.
  3. Leading and trailing edges of vertical blanking (pedestal) should be complete in less than 0.1H.
  4. Leading and trailing edges of horizontal blanking (pedestal) shall be steep enough to preserve min. and max. values of durations under all conditions of picture content.
  5. All tolerances and limits shown in this drawing are permissible only for long-time variations.
  6. Equalizing pulse area shall be between 0.45 and 0.5 of the area of a horizontal sync pulse.
  7. All rise and decay times shall measure between 0.1 and 0.9 amplitude reference lines.
  8. The overshoot on blanking (pedestal) signal shall not exceed 0.02B at the beginning of the front porch and shall not exceed 0.05B at the end of the back porch. The overshoot on sync signals shall not exceed 0.05B. Any other overshoot on the blanking (pedestal) signal shall not exceed 0.02B.
  9. For setting aspect ratio, the horizontal blanking (pedestal) duration should be set to 0.173H at the 0.5B point.
  10. Rise time and decay time of horizontal blanking shall not exceed 0.003H.

RISE TIME & DECAY TIME OF ALL PULSES 0.003H MAX.  
(SEE NOTE 7)

Figure 3-1. Standard Commercial Television Format

pre-emphasis for this system above threshold. However, it is anticipated that TV transmission may be conducted below the ground receiver threshold due to unexpected link degradation or by design. The design decision on the use of pre-emphasis will therefore be deferred until the results of the demonstration survey are presented in paragraph 10.2.

In order to adequately define the requirements which the video channel must meet, a search of the available literature was performed. There is a great deal of literature on this subject (for example, references 3.2, 3.3, and 3.4); however, the information was not in general found to be directly applicable to the CAT Relay Experiment. For example, noise interference tests were typically conducted with a 4 MHz bandwidth with either additive flat Gaussian noise or over an actual vestigial side band broadcast link. The transmission system which is being designed, an FM system near threshold, will have non-flat and non-Gaussian noise -- the majority of interference being impulsive in character. Also, a system design goal will be to narrow the bandwidth to about 2 MHz for link conservation in contrast to the usual commercial systems which utilize bandwidths in excess of 4 MHz. A second system goal is to avoid transmission of the dc component of the TV video.

Generally, the outcome of past studies were not conclusive, nor did they agree with Motorola's laboratory experience along this line. Other requirements for FM systems (references 3.5, 3.6, and 3.7) exist for distortionless and essentially noiseless radio relay repeater purposes as used on the national network distribution system such as the TD-2, TH, and TJ relays of the Bell System. Because the AAC-ATS-ATS Ground is an end link, the r-f power is limited and no color transmission requirements must be met (not usually the case for radio relay repeaters), thus the usual commercial requirements as commonly stated are unnecessarily stringent. In short, the available literature was not found to be usable, and it was obvious that to ameliorate this problem some laboratory work would be needed to define the video requirements empirically.

The necessary requirements to assure reasonable video transmission which will be considered are received signal-to-noise ratio, link bandwidth, and link non-linearities. The signal-to-noise (SNR) usually associated with commercial television is quite satisfactory for viewing and will be duplicated if economically reasonable. For TV SNR measurement the signal is measured on a peak-to-peak basis from white peak to sync pulse tip. The noise is measured using a weighting filter network or in the demodulator post-detection bandwidth using an rms meter. The resulting SNR is known as peak-to-peak signal to weighted rms noise (SNRW) when measured with the weighting filter or as peak-to-peak/rms SNR (also rms/rms SNR) when measured in the full post-detection bandwidth. Noise weighting consists of measuring the received noise with a standard monochrome low pass filter network<sup>3.8</sup> and has the

effect of weighting the high frequency noise in a manner similar to the human eye. Thus, weighted SNR improvements are more directly related to humanly perceptible increase in picture quality.

The r-f noise bandwidth is assumed fixed at 20 MHz. This original program constraint provides the starting point for the system design. As it turns out, 20 MHz bandwidth is a reasonable choice and reduction of this bandwidth does not provide any SNR advantage. A few comments on the video signal characteristics are in order. First, the video spectral density has the majority of the energy within the lower 500 kHz of bandwidth as shown in Figure 3-2<sup>3, 9</sup>. Secondly, the estimated probability density function for the composite video (Figure 3-3), shows that the peak-to-peak voltage is only achieved a very small percent of the time. The ramification of these two considerations is to allow a higher peak frequency deviation than would otherwise be allowed because the over-load only occurs infrequently and therefore does not cause prohibitive distortion. The addition of the sound subcarrier is assumed to not increase the video distortion beyond tolerable limits. A conservative tolerable limit is about 2 db linearity compression<sup>3, 7</sup>. This assumption is shown to be valid from laboratory tests. The effect of the sound subcarrier on the main carrier is calculated to be less than 0.1 db and may be ignored.

The drift in the transmitter oscillator will be specified as  $\pm 100$  ppm consistent with the expected Motorola Wideband Transmitter stability performance. The total downlink FM frequency uncertainty is estimated as follows:

Transmitter oscillator	=	$\pm 225$ kHz
Carrier doppler	=	$\pm 45$ kHz
ATS-F frequency translation	=	$\pm 5$ kHz
Unallocated tolerance	=	$\frac{450}{2}$ kHz
Total p-p uncertainty		1000 kHz

The maximum frequency deviation can now be calculated using Carson's Rule

$$\Delta f = \frac{BW_{if} - 2f_b - f_u}{2}$$

where  $f_b = 500$  kHz, the maximum baseband modulation frequency of importance,

$f_u = 1$  MHz, the total uncertainty (p-p),

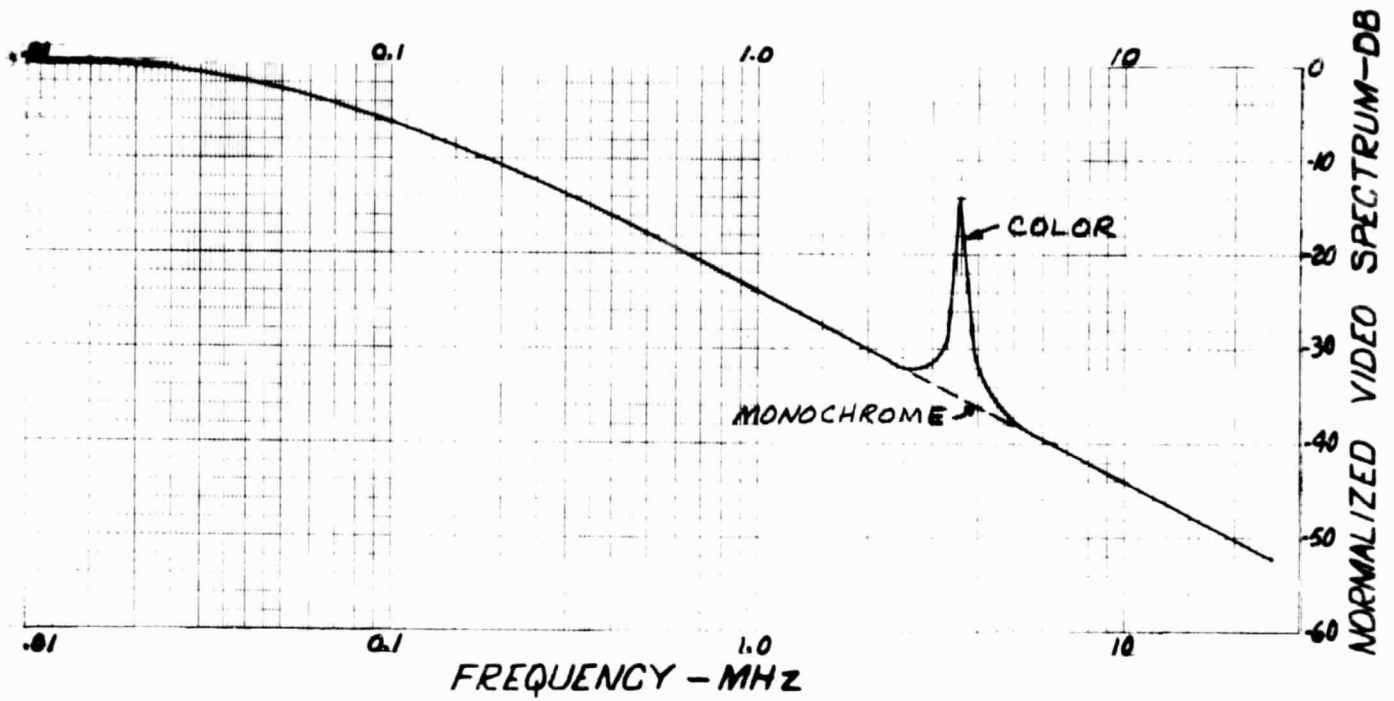


Figure 3-2. Estimated Video Spectrum

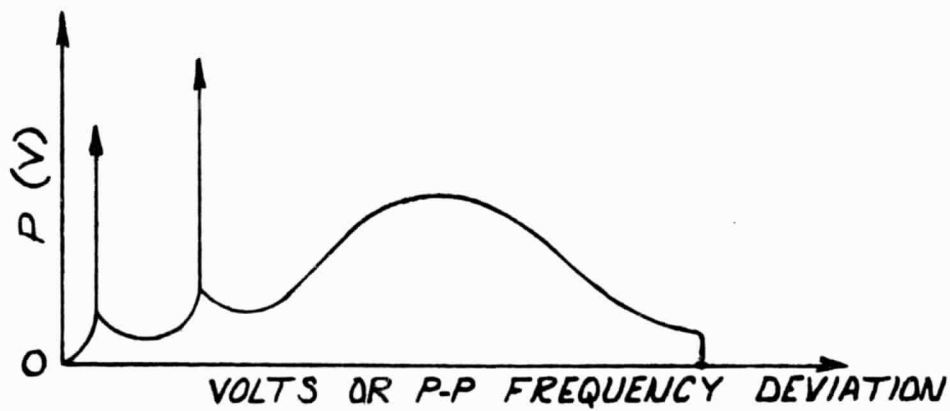


Figure 3-3. Estimated Probability Density Function for Monochrome Video

$$BW_{if} = 20 \text{ MHz}$$

then  $\Delta f = 9 \text{ MHz}$

Using this value for peak frequency deviation, the post detection signal-to-noise ratio can be found for a near threshold condition. The 1 db threshold is assumed to be 9 db. The SNR is:

$$S_{p-p}/N_{rms} = \frac{12}{D} \frac{\Delta f^2}{f_T^2} (\text{CNR}) \frac{BW_{IF}}{f_T} \text{ (above threshold)}$$

For  $\Delta f = 9 \text{ MHz}$  peak deviation

$D =$  threshold degradation (0.5 db)

$BW_{IF} = 20 \text{ MHz}$  (predetection bandwidth)

$f_T = 2 \text{ MHz}$  (postdetection bandwidth)

CNR = 10 db in the i-f bandwidth

Then  $S_{p-p}/N_{rms} = 43.4 \text{ db}$

Thus within these assumed constraints, a weighted signal-to-noise ratio (SNRW) of 50.5 db can be obtained by further assuming that the ATS ground station demodulator has a SNR characteristic identical to Figure 3-4. By jumping ahead and reviewing the results of the quality survey from the demonstration (Table 10-1), it is apparent that 50.5 db is a high quality signal which about 60% of the viewers would rate as excellent in quality (per Figure 10-2 definition).

In order to conserve link r-f power, it appears reasonable to also investigate the link performance using a threshold extension demodulator (TED) in the ATS ground station. This TED is assumed to have a 6 db threshold and the relative SNR characteristic given in Figure 3-5 as such units are available from several suppliers. By dropping the potential operating point to 7 db CNR, the resulting SNR becomes 40 db unweighted and approximately 47.5 db weighted (SNRW). Again referring to the Table 10-1 survey results, it is estimated that 85% of the viewers would consider this a fine/excellent picture. Actual observations from the laboratory system would indicate that the picture quality may be better than extrapolated from Table 10-1 since operation of the TED is above threshold and thus impulsive or click noise will not be so evident.

The net conclusion of the modulation analysis and laboratory testing is to design the CAT Relay System for a worst case minimum picture quality of 47.5 db SNRW with a design goal of 50.5 db SNRW or better picture quality for at least 50% of the Experiment transmission time. The corresponding

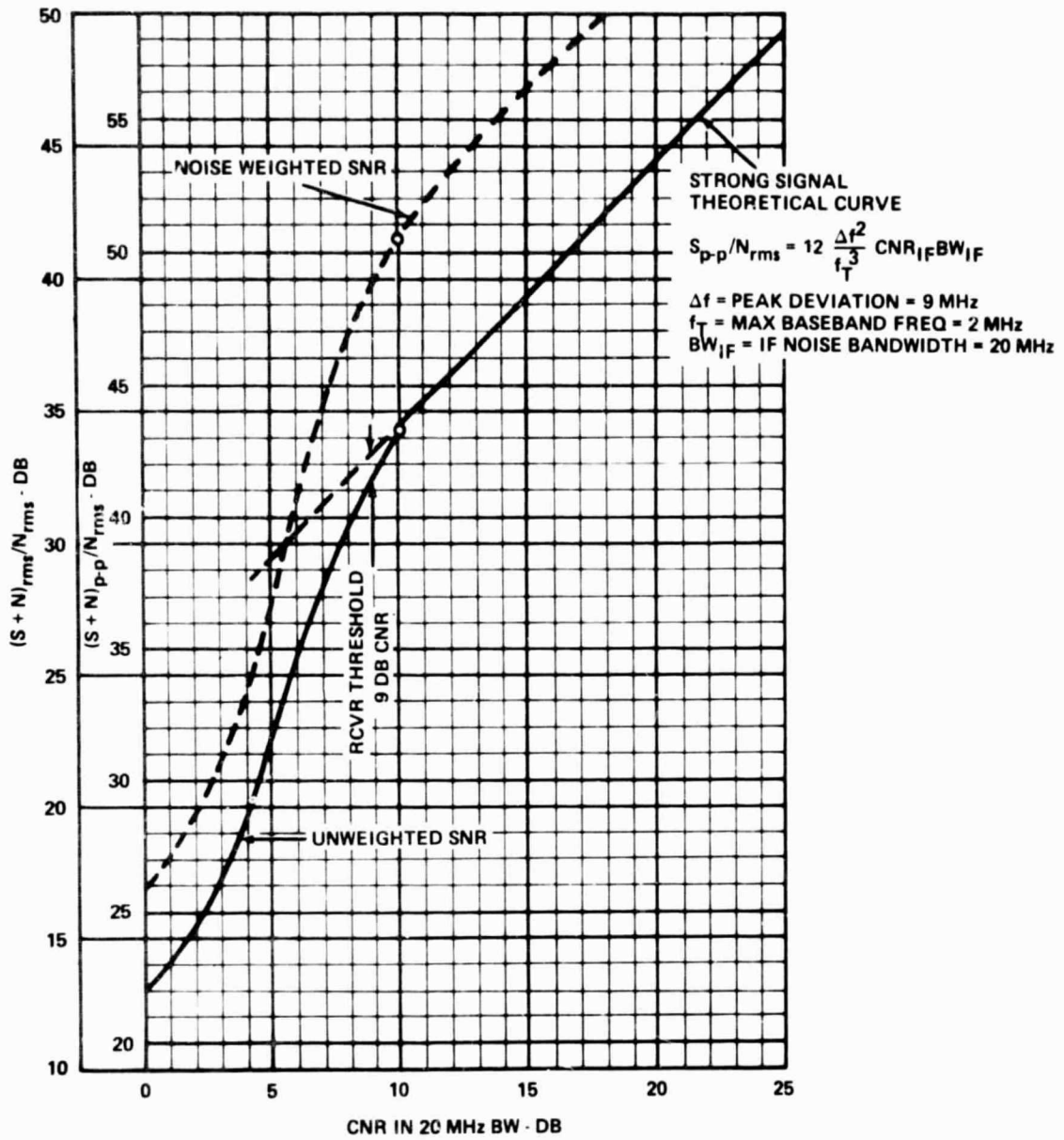


Figure 3-4. Assumed Signal-to-Noise-Ratio (SNR) at Baseband - ATS Ground Station

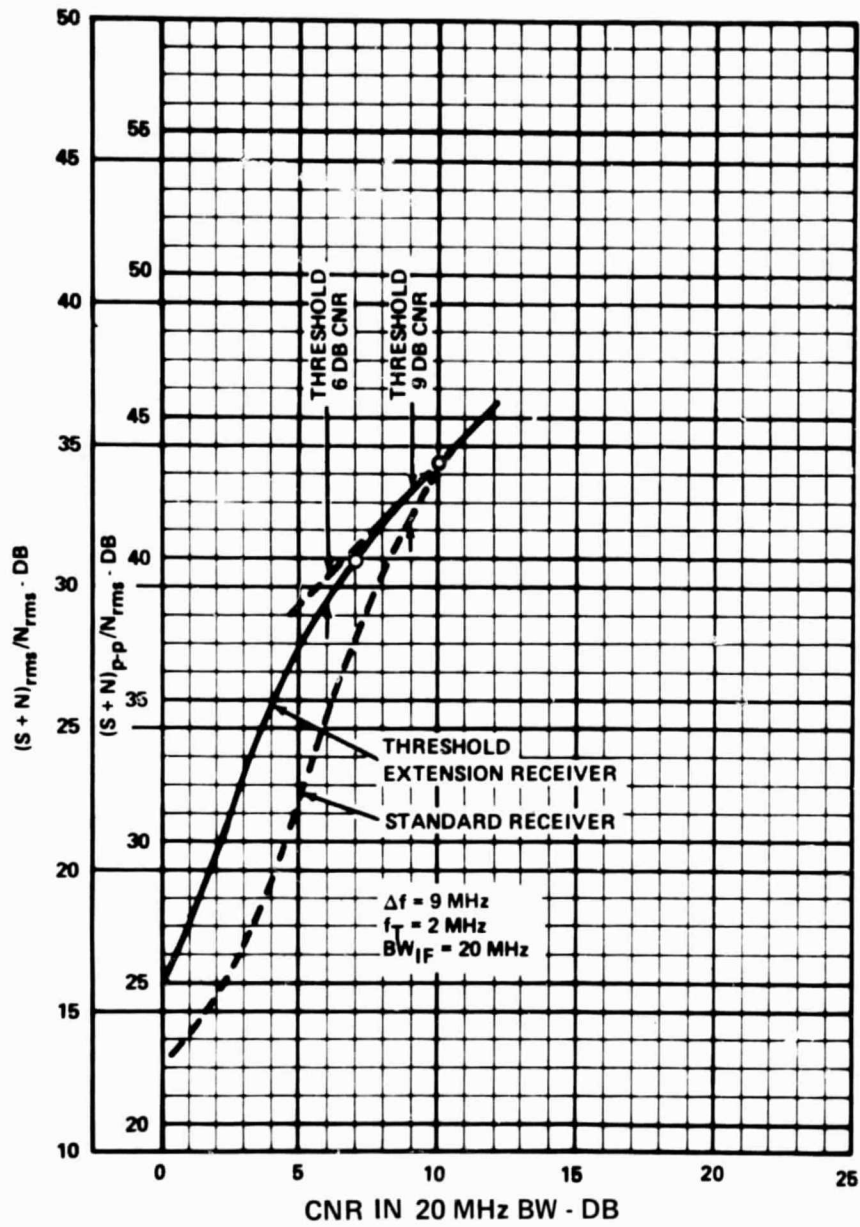


Figure 3-5. Assumed SNR Characteristic Threshold Extension Demodulator

downlink carrier to noise density requirements are 80 db-Hz and 83 db-Hz respectively. The use of video pre-emphasis is not required for the Experiment since it does not perceptibly improve monochrome television quality above threshold. The value of pre-emphasis below threshold is evaluated in paragraph 10.2. Pre-emphasis enhances the higher frequency SNR and is usually only used in color television transmission where significant color subcarrier energy exists up to 4.2 MHz, and therefore SNR improvement of the color subcarrier can be obtained.

### 3.1.2 Crew Voice Transmission Requirements

The crew voice channel being transmitted along with the video also requires analysis and definition. Fast IRE studies<sup>3.3</sup> have indicated that the general public will be much more satisfied with a poor video image and good sound than the inverse situation. For this reason alone, the voice channel should be fairly good. Using the design approach defined herein to transmit the voice channel, the video channel suffers only about 0.1 db degradation to provide more than 50 db peak signal to rms noise in the 3 kHz voice channel. Since the voice channel quality is more critically important on a subjective basis, the cost of providing a good voice channel appears to be an excellent bargain.

The crew voice channel pre-detection noise bandwidth was assumed to be 100 kHz partly for convenience and partly because the commercial broadcast systems use 100 kHz. The subcarrier frequency was selected to be 4.5 MHz also because of convenience and because it provides satisfactory performance. A criterion of above threshold operation was considered necessary for the voice channel. The 1 db threshold is assumed to be 10 db CNR in the 100 kHz pre-detection bandwidth (i. e. SCNR = 10 db, subcarrier rms to noise rms). Now the required deviation of the main carrier can be determined.

$$SCNR = \frac{3}{2} \frac{f_c^2}{f_U^3 - f_L^3} (CNR)_{IF} \frac{BW_{IF}}{D}$$

Where  $D$  = threshold degradation (1 db)

$$SCNR = CNR = 10 \text{ db}$$

$$f_U = \text{upper band frequency (4.55 MHz)}$$

$$f_L = \text{lower band frequency (4.45 MHz)}$$

$$BW_{IF} = 20 \text{ MHz predetection bandwidth}$$

$$\text{Then } \Delta f_c = \frac{2(f_U^3 - f_L^3) D}{3 BW_{IF}}$$

$$\Delta f_c = 402 \text{ kHz.}$$

The required deviation for the assumed operation is 402 kHz peak. As pointed out previously, this peak deviation increases the probability of overload in the receiver but not sufficiently to degrade the demodulated video. The reduction of the main carrier is given by  $20 \log J_0 \left( \frac{0.87}{4.5} \right) \cong 0.08$  db which is an insignificant amount.

The detected voice channel can have the low pass filter at any point after the detector. The post detection bandwidth has been selected as 3 kHz. The frequency uncertainty of the subcarrier consists of:

Subcarrier tolerance ( $\pm 0.2\%$ )	=	<u>+9.0 kHz</u>
Doppler shift	=	<u>+0.2 kHz</u>
Unallocated	=	<u>5.6 kHz</u>
Total subcarrier uncertainty	=	24.0 kHz

$$\text{Then } \Delta f_s = \frac{BW_{SIF} - 2f_v - f_{su}}{2}$$

where  $f_v = 3$  kHz, the maximum voice frequency,  
 $f_{su} = 24$  kHz, the total subcarrier uncertainty (p-p)  
 $BW_{SIF} = 100$  kHz  
and  $\Delta f_s = 35$  kHz.

For a 3 kHz low pass, the post detection peak signal to noise rms is:

$$\frac{S_{\text{peak}}}{N_{\text{rms}}} = \frac{3\Delta f_s^2}{f_v^2} \quad (\text{SCNR}) \quad \frac{BW_{SIF}}{f_v}$$

$$\text{SCNR} = 10 \text{ db}$$

$$\Delta f_s = 35 \text{ kHz subcarrier peak deviation}$$

$$f_v = 3 \text{ kHz post detection bandwidth}$$

$$BW_{SIF} = 100 \text{ kHz predetection bandwidth}$$

$$S_{\text{peak}}/N_{\text{rms}} = 51.4 \text{ db}$$

Subsequent laboratory system evaluation of the voice/video SNR tradeoff (Figure 4-12) indicates a significant improvement can be made in the voice link (about 13 db) by increasing the subcarrier deviation to 1 MHz peak. At the same time, the video SNR degradation is only 0.5 db. Thus, the recalculated  $S_{pk}/N_{rms}$  at 1 MHz peak deviation of the carrier is 59.4 db.

### 3.1.3 Design Summary

The recommended CAT Relay design parameters as a result of the analysis and evaluation of particular laboratory system test results are listed in Table 3-1. These parameters may be revised by equipment and operational constraints.

Table 3-1. CAT Relay Experiment Design Parameters  
TV/Crew Voice Link

<u>TV Transmission</u>	
Video Format	EIA RS-170
Modulation Method	FM
Pre-Emphasis	None
Predetection Bandwidth	20 MHz
Transmitter Frequency Stability	$\pm 100$ ppm
Carrier Deviation	$\pm 9$ MHz peak
Post Detection Bandwidth	2 MHz
Demodulator Threshold	6 db CNR
Worst Case Operation	
Operating CNR	7 db
Post Detection SNRW	47.5 db p-p/rms
Downlink Carrier to Noise Density Ratio	80 db-Hz
Operation Goal for 50% of the Transmission	
Operating CNR	10 db minimum
Post Detection SNRW	50.5 db p-p/rms
Downlink Carrier to Noise Density Ratio	83 db-Hz
Transfer Linearity - Compression at Operating Point	2 db maximum

Table 3-1. CAT Relay Experiment Design Parameters  
TV/Crew Voice Link (cont)

<u>Crew Voice Transmission</u>	
FM Subcarrier Frequency	4.5 MHz
Predetection Bandwidth	100 kHz
Subcarrier Frequency Stability	$\pm 0.2\%$
Carrier Deviation	$\pm 1$ MHz peak
Subcarrier CNR	18 db
Subcarrier Deviation	$\pm 35$ kHz peak
Post Detection Bandwidth	3 kHz
Post Detection SNR	59.4 db pk/rms

### 3.2 R-F TRANSMISSION

The CAT Relay Experiment involves four major r-f transmission paths - to and from the ATS-F and AAC, and to and from ATS-F and the ATS Ground Station. Two operating mode bandwidths are required - wide (6 to 40 MHz) and narrow (less than 500 kHz). Since the transmission of the TV/voice downlink presents the demanding link design, it will be analyzed in detail in this section along with the wideband uplink requirements. The narrowband back-up voice links will be analyzed in the next section. The following analyses are based upon the recommended basic system discussed in Section 6.

#### 3.2.1 Wideband Downlink Design

The AAC to ATS-F and ATS-F to ATS Ground link characteristics are summarized in Table 3-2 for the 15<sup>o</sup> ATS-F conical coverage described in paragraph 2.2. The ATS-F to ATS Ground link parameters are derived from references 3.10 and 3.11 and Section 2 fundamentals. The all-parameters-worst-case carrier to noise density ratio for the ATS-F to ground section of the downlink is 89.3 db-Hz and is a basic limitation on the downlink TV quality possible. The tolerance values are estimated and result in an all-best-case density of 94.3 db-Hz.

Table 3-2 lists the AAC to ATS-F link characteristics based upon an 11 watt (10.4 DBW) S-band transmitter and a 10 foot parabolic antenna (34 db gain at the feed). Circuit losses assumed are summarized in Section 5. The estimated all-parameters-worst-case AAC to ATS-F link carrier to noise density ratio is 81.7 db-Hz and could be as high as 91.8 db-Hz for best case. Figure 3-6 graphically illustrates the net increase required in the

TABLE 3-2. DOWNLINK PARAMETERS USING S

FUNCTIONS AND PARAMETERS	AAP SPACEGRAFT		ATS-F RECEIVE		ATS-F TRAN
	TRANSMIT CHARACTERISTICS		CHARACTERISTICS		CHARACTERIS
	VALUE	TOL	VALUE	TOL	VALUE
<b>A. FREQUENCY (INCLUDING DOPPLER)</b>					
COHERENT PM	2247.8 MHz	±49.2 kHz	2247.8 MHz	±98.4 kHz	7283.0 MHz ±
NONCOHERENT PM	2247.8 MHz	±67.4 kHz	2247.8 MHz	±116.6 kHz	7283.0 MHz ±
FM	2253.0 MHz	±225 kHz	2253.0 MHz	±274.5 kHz	7300.0 MHz ±
<b>B. IF NOISE BANDWIDTH</b>	—		40.0 MHz	+0 -10 MHz	—
<b>C. XMITR OUTPUT POWER</b>	40.4 DBM	+0.4 -0 DB	—		43.8 DBM
<b>D. XMIT CIRCUIT LOSS</b>	3.5 DB	+0 -0.7 DB	—		2.0 DB
<b>E. BROADBEAM ANTENNA</b>					
BORESIGHT GAIN	—		—		18.0 DB
0.5 PWR BEAMWIDTH	—		—		20°
POINTING LOSS	—		—		2.2 DB
<b>F. STEERABLE ANTENNA</b>					
BORESIGHT GAIN	34.0 DB	+0.5 -0 DB	41.0 DB	+2.0 -0 DB	—
0.5 PWR BEAMWIDTH	30°	—	1.0°	—	—
SCAN ANGLE	AZ: 8.7° EL: 10.4°	MIN	15° CONICAL	MIN	—
SCAN LOSS	0		3.0 DB	+0 -3.0 DB	—
POINTING ACCURACY	0.2 BEAMWIDTH	MAX	0.2 BEAMWIDTH	MAX	—
POINTING LOSS	0.5 DB	+0 -0.5 DB	0.5 DB	+0 -0.5 DB	—
<b>G. POLARIZATION</b>	RCP		RCP		RCP
LOSS	—		0.5 DB	+0 -0.5 DB	—
<b>H. PATH LOSS</b>	—		191.7 DB	+0 -0.8 DB	—
<b>I. RCVE CIRCUIT LOSS</b>	—		3.0 DB	+0 -1.0 DB	—
<b>J. RCVR INPUT LEVEL</b>	—		-87.3 DBM	+7.8 -0 DB	—
<b>K. RCVR SYS NOISE FIGURE</b>	—		5.0 DB	+0 -1.0 DB	—
NOISE TEMP	—		—		—
<b>L. CIN DENSITY RATIO</b>	—		81.7 DB-Hz	+10.1 -0 DB	—
<b>M. DOWNLINK CIN DENS. RATIO</b>	—		—		—
<b>N. IF SNR</b>	—		5.7 DB	+11.3 -0 DB	—

ING STEERABLE ANTENNA SUBSYSTEM

				MOJAVE - MSFN INTERSITE			
TRANSMIT		MOJAVE RECEIVE		MOJAVE TRANSMIT		MSFN RECEIVE	
CHARACTERISTICS		CHARACTERISTICS		CHARACTERISTICS		CHARACTERISTICS	
VALUE	TOL	VALUE	TOL	VALUE	TOL	VALUE	TOL
MHz	± 98.5 kHz	7283.0 MHz	± 98.5 kHz	BASEBAND		BASEBAND	
MHz	± 116.6 kHz	7283.0 MHz	± 116.6 kHz	BASEBAND		BASEBAND	
MHz	± 274.5 kHz	7300.0 MHz	± 274.5 kHz	---		---	
		20.0 MHz	± 0.5 MHz				
DBM	+0.2 -0 DB	---					
DB	+0 -1.0 DB	---					
DB	+0.5 -0 DB	---					
		---					
DB	+0 -0.7 DB	---					
		56.0 DB	+1.0 -0 DB				
		?	---				
		AS REQ'D	---				
		0	---				
		.01 BEAMWIDTH	MAX				
		0					
		RCP					
		0.5 DB	+0 -0.5 DB				
		202.4 DB	+0 -0.7 DB				
		0.1 DB	+0 -0 DB				
		- 89.4 DBM	+4.6 -0 DB				
		- 4.7 DB	+0 -0.4 DB				
		100° K	+0 -10° K				
		89.3 DB-Hz	+5.0 -0 DB				
		81.0 DB-Hz	+8.9 -0 DB			81.0 DB-Hz	+8.9 -0 DB
		7.9 DB	+9.1 -0 DB				
							12-22-68

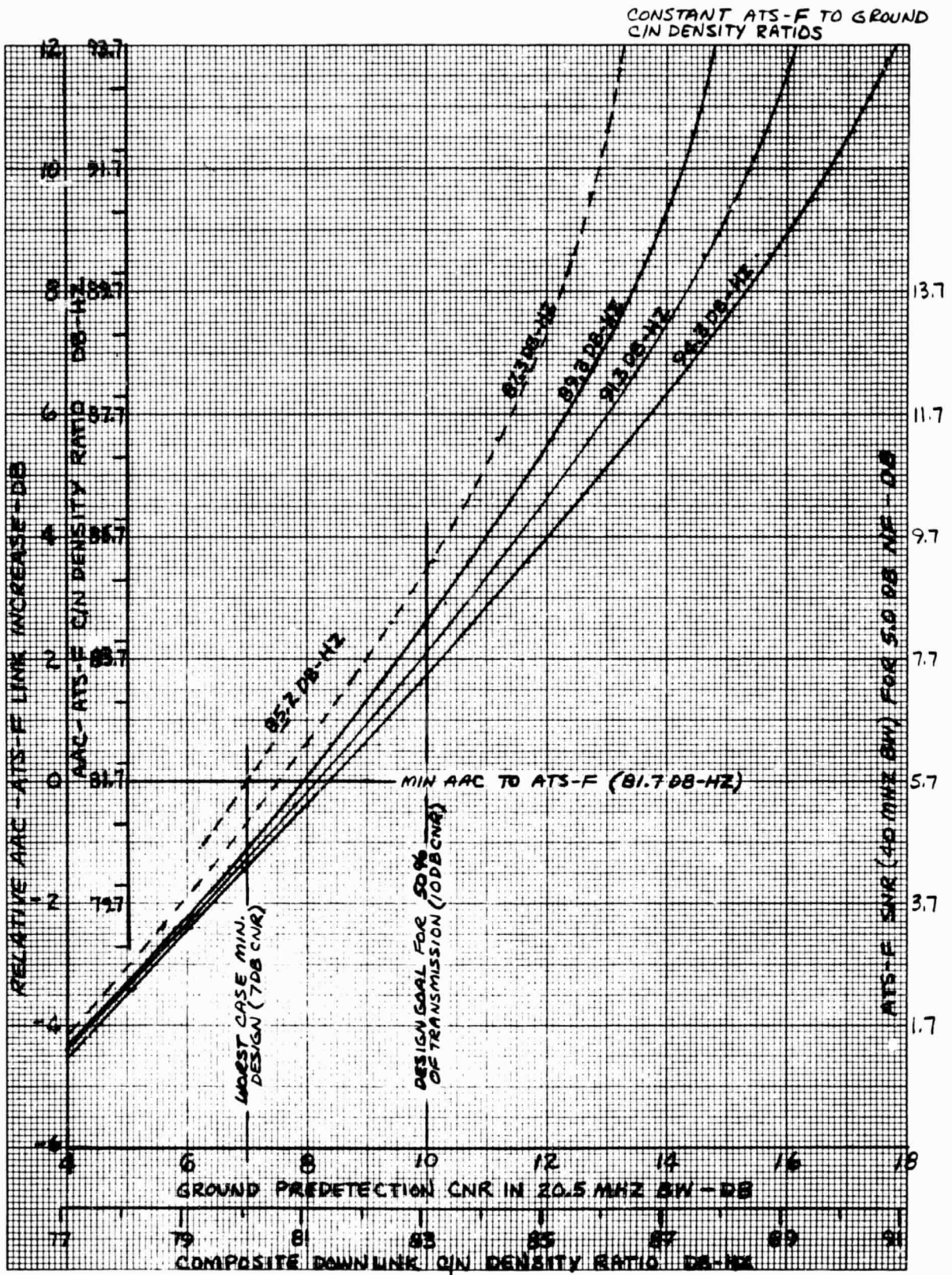


Figure 3-6. Effect of Two Links on Composite Downlink CNR

AAC to ATS-F link in order to obtain received CNR improvement at the ATS Ground Station. In order to obtain 10 db minimum CNR at the ground, the AAC to ATS-F link must be increased by 1.7 to 2.6 db over the worst case level of 81.7 db-Hz.

### 3.2.2 Wideband Uplink Design

The ATS Ground Station to ATS-F and ATS-F to AAC link characteristics are summarized in Table 3-3 for the 15° ATS-F conical coverage. ATS Ground to ATS-F is again the strongest link as determined from references 3.10 and 3.11 providing 90.9 to 104.8 db-Hz assuming up to 5 KW is available at the Ground Station. The ATS-F to AAC is based upon the 10 foot parabolic reflector on the AAC and a 5.5 db NF S-band preamplifier. The estimated all-parameters-worst-case ATS-F to AAC link carrier to noise density ratio is 78.2 db-Hz increasing to 88.2 db-Hz for all best case. Figure 3-7 shows the increase in ATS-F to AAC link requirements for increasing the overall link density. The limiting factor in this link is the strong signal noise figure increase of the SGLS Receiver (see paragraph 4.5 for discussion).

### 3.2.3 Uplink Summary

The wideband link calculations have previously been estimated by Laughlin and Heffernan<sup>3.12</sup> and Pickard, et al<sup>3.11</sup> but without as much detailed information. Table 3-4 is compiled to allow easy comparison of all these estimates.

## 3.3 BACK-UP VOICE MODES

It is very desirable to have back-up voice transmission and reception capability for emergency use. This capability would be even more attractive if it could be implemented with spherical omni antenna coverage on the AAC so the links could be used when the AAC assumes any attitude or is tumbling. However, providing spherical antenna patterns from the AAC is a very difficult design problem involving proper phasing of more than one AAC omni-antenna or some other solution in order to eliminate all "blind" areas created by vehicle shadowing. The design of simultaneous spherical omni antenna coverage is not considered to be within the scope of this program. In lieu of this coverage, the CAT Relay Experiment has been designed with two switchable omni-antennas, 180° apart on the AAC, in order to allow experimental check out of the low antenna gain links and provide the basis for a future emergency link design which might include spherical antenna patterns. The omni-antennas assumed for the experiment provide a minimum of 1 db of gain over 50% of a sphere and are described in more detail in paragraph 6.2.

TABLE 3-3 UPLINK PARAMETERS USING

FUNCTIONS AND PARAMETERS	AAP SPACECRAFT		ATS-F TRANSMIT		ATS-F RECE
	RECEIVE CHARACTERISTICS		CHARACTERISTICS		CHARACTERIS
	VALUE	TOL	VALUE	TOL	VALUE
A. FREQUENCY (INCL. DOPPLER)	1800.0 MHz	±39.5 kHz	1800.0 MHz	±100 Hz	8000.0 MHz ±
B. IF NOISE BANDWIDTH	6.0 MHz	± 0.5 MHz	—	—	20.0 MHz
C. XMTR OUTPUT POWER	—	—	40.0 DBM	+1.0 -0 DB	—
D. CIRCUIT LOSSES (XMIT)	—	—	3.0 DB	+0 -1.0 DB	—
E. BROADBEAM ANT.					
BORESIGHT GAIN	—	—	—	—	18.0 DB
0.5 PWR BEAMWIDTH	—	—	—	—	20°
POINTING LOSS	—	—	—	—	2.2 DB
F. STEERABLE ANTENNA					
BORESIGHT GAIN	32.0 DB	+0.5 -0 DB	39.0 DB	+2.0 -0 DB	—
0.5 PWR BEAMWIDTH	3.8°	—	1.3°	—	—
SCAN ANGLE	AZ: 8.7° EL: 10.4°	MIN	15° CONICAL	MIN	—
SCAN LOSS	0	—	3.0 DB	+0 -3.0 DB	—
POINTING ACCURACY	0.2 BEAMWIDTH	MAX	0.2 BEAMWIDTH	MAX	—
POINTING LOSS	0.5 DB	+0.5 -0.5 DB	0.5 DB	+0 -0.5 DB	—
G. POLARIZATION	RCP	—	RCP	—	RCP
LOSS	0.5 DB	+0.5 -0.5 DB	—	—	0.5 DB
H. PATH LOSS	189.8 DB	+0 -0.8 DB	—	—	203.2 DB
I. CIRCUIT LOSS (RCVE)	3.7 DB	+0.5 -0.5 DB	—	—	2.0 DB
J. PREAMP INPUT LEVEL	-90.0 DBM	+10.3 -0 DB	—	—	—
K. PREAMP/CABLE NET GAIN	14.0 DB	+2.5 -0 DB	—	—	—
L. RECEIVER INPUT LEVEL	-76.0 DBM	+17.8 -0 DB	—	—	-76.1 DBM
M. RCVE SYS NOISE FIG	5.8 DB	+2.5 -0.1 DB	—	—	7.0 DB
N. C/N DENSITY RATIO	78.2 DB-Hz	+10.0 -0 DB	—	—	90.9 DB-Hz
O. UPLINK C/N DENS. RATIO	78.0 DB-Hz	+10.3 -0 DB	—	—	—
P. IF SNR	9.9 DB	+11.0 -0 DB	—	—	17.9 DB

NG STEERABLE ANTENNA SUBSYSTEM

		MOJAVE-MSFN INTERSITE					
		←					
RECEIVE		MOJAVE TRANSMIT		MOJAVE RECEIVE		MSFN TRANSMIT	
CHARACTERISTICS		CHARACTERISTICS		CHARACTERISTICS		CHARACTERISTICS	
TOL		VALUE		TOL		VALUE	
TOL		TOL		TOL		TOL	
Hz	± 100 Hz	8000.0 MHz	± 100 Hz	BASEBAND		BASEBAND	
Hz	MIN	—	—				
		57.0 DBM	+10 -0 DB				
		0.2 DB	+0 -0 DB				
B	+0.5 -0 DB	—	—				
B	—	—	—				
B	+0 -0.7 DB	—	—				
		57.0 DB	+0.5 -0 DB				
		AS REQ'D	—				
		0	—				
		.01 BEAMWIDTH	MAX				
		0	—				
		RCP	—				
B	+0 -0.5 DB	—	—				
B	+0 -0.7 DB	—	—				
B	+0 -0.5 DB	—	—				
		—	—				
BM	+13.4 -0 DB	—	—				
B	+0 -0.5 DB	—	—				
-Hz	+13.9 -0 DB	—	—				
B	+13.9 -0 DB	—	—				

12-22-68



Table 3-4. C/N Density Ratio Estimates

All values in db-Hz

Data Source	Uplink			Downlink		
	Ground to ATS-F	ATS-F to AAC	Ground to AAC	AAC to ATS-F	ATS-F to Ground	AAC to Ground
Laughlin and Heffernan Reference 3.12, para - graph 3.4	106.1	69.2	69.2	89.6	89.6	69.6
Pickard, et al, Ref- erence 3.11, Table 3-2	85.6	83	81.3	92.5	92.9	89.7
Tables 3-2 and 3-3	90.9 +13.9 - 0	78.2 +10.0 - 0	78.0 +10.3 - 0	81.7 +10.1 - 0	89.3 +5.0 -0	81.0 +8.9 -0

The most efficient emergency voice transmission has been assumed to be the USBS Back-Up Voice mode of operation. The mode involves the following parameters:<sup>3.13</sup>

Frequency response	300 to 2300 Hz
Pre-emphasis	6 db/octave
Clipping level	24 db
Carrier phase deviation	1.2 radians
Predetection noise bandwidth	7010 Hz $\pm$ 680 Hz
Predetection SNR required	4.27 db
Post detection bandwidth	200 to 2500 Hz
Post detection noise bandwidth	160 to 3000 Hz
Post detection SNR for 70% intelligibility	4 db

Table 3-5 is the downlink parameter summary using this mode of operation from the AAC to the ATS Ground Station through the ATS-F. The ATS-F to ground link is unchanged from that presented in Table 3-2 and is therefore not repeated. It can be seen that for simultaneous all-worst-case conditions, this link would apparently have 1.5 db margin and could provide as high as 14.5 db margin at some portions of the AAC orbital pass. The Motorola recommended basic CAT Relay System detailed in Section 6 includes the capability for this downlink back-up voice mode (DOWN PM MODE 7).

The provision of an operational uplink back-up voice mode is not as easily provided. The basic CAT Relay System is not envisioned to carry uplink carrier modulation below the 30 kHz up-voice channel. The narrow-band tracking loops on the ATS-F uplink receiver and the AAC uplink receiver will track out a significant portion of the voice spectrum if phase modulated directly on the uplink carrier. In the interest of evaluating a potential uplink back-up voice operating mode (UP MODE 9), the proper modifications to the ATS-F and AAC receivers have been assumed and the expected link parameters given in Table 3-6. The link analysis as shown indicates that marginal capability would be encountered for all-worst-case link tolerances. This fact, in addition to the narrow receiver bandwidth problem cited earlier, leads us to conclude that this operating link should be studied in more detail in the next CAT Relay program phase and adequate link, performance and equipment changes defined at that time for uplink back-up voice capability.

TABLE 3-5. DOWNLINK PARAMETERS USING OMNI-ANTENNAS

FUNCTIONS AND PARAMETERS	AAP SPACECRAFT		ATS-F RECEIVE	
	TRANSMIT CHARACTERISTICS		CHARACTERISTICS	
	VALUE	TOL	VALUE	TOL
<b>A. FREQUENCY (INCLUDING DOPPLER)</b>				
COHERENT PM	2247.8 MHz	±49.2 kHz	2247.8 MHz	±98.4 kHz
NONCOHERENT PM	2247.8 MHz	±67.4 kHz	2247.8 MHz	±116.6 kHz
<b>B. IF NOISE BANDWIDTH</b>	—		250 kHz	
<b>C. XMTR OUTPUT POWER</b>	40.4 DBM	+0.4 DB -0 DB	—	
<b>D. XMIT CIRCUIT LOSS</b>	4.0 DB	+0 DB -1.0 DB	—	
<b>E. OMNI-ANTENNA</b>				
GAIN OVER 50% SPHERE	1.0 DB	+2.0 DB -0 DB	—	
<b>F. STEERABLE ANTENNA</b>				
BORESIGHT GAIN	—		41.0 DB	+2.0 DB -0 DB
0.5 PWR BEAMWIDTH	—		1.0°	
SCAN ANGLE	—		15° CONICAL	MIN
SCAN LOSS	—		3.0 DB	+0 DB -3.0 DB
POINTING ACCURACY	—		0.2 BEAMWIDTH	MAX
POINTING LOSS	—		0.5 DB	+0 DB -0.5 DB
<b>G. POLARIZATION</b>	RCP		RCP	
LOSS	—		0.5 DB	
<b>H. PATH LOSS</b>	—		191.7 DB	+0 DB -0.8 DB
<b>I. RCVE CIRCUIT LOSS</b>	—		3.0 DB	
<b>J. RCVR INPUT LEVEL</b>	—		-120.3 DBM	+12.2 DB -0 DB
<b>K. RCVR SYS NOISE FIGURE</b>	—		5.0 DB	+0 DB -1.0 DB
<b>L. L2RAD BACK-UP VOICE</b>				
MODULATION LOSS	3.0	—	—	
LIMITER SNR LOSS (IF)	—		1.1 DB	+0 DB -1.0 DB
<b>M. C/N DENSITY RATIO</b>	—		44.6 DB	+12.2 DB -0 DB
<b>N. NOISE BANDWIDTH</b>	—		(7.7 kHz) 38.8 DB	+0 DB -0.8 DB
<b>O. RECEIVED SNR</b>	—		* 5.8 DB	+13.0 DB -0 DB
<b>P. REQ'D SNR (70% INTELL)</b>	—		4.3 DB	MIN
<b>Q. MARGIN</b>	—		1.5 DB	+13.0 DB -0 DB

\* ATS-F TO MOJAVE LINK DOES NOT DEGRADE THIS VALUE.

TABLE 3-6 UPLINK PARAMETERS USING OMNI-ANTENNAS

FUNCTIONS AND PARAMETERS	←			
	AAP SPACECRAFT		ATS-F TRANSMIT	
	RECEIVE CHARACTERISTICS		CHARACTERISTICS	
	VALUE	TOL	VALUE	TOL
A. FREQUENCY (INCL. DPPOLER)	1800.0 MHz	±39.5 kHz	1800.0 MHz	±100 Hz
B. IF NOISE BANDWIDTH	6.0 MHz	±0.5 MHz	250.0 kHz	MIN
C. XMTR OUTPUT POWER	-		40.0 DBM	+1.0 DB -0.0 DB
D. XMIT CIRCUIT LOSS	-		3.0 DB	±0.0 DB
E. OMNI-ANTENNA				
GAIN OVER 50% SPHERE	1.0 DB	+2.0 DB -0.0 DB	-	
F. STEERABLE ANTENNA				
BORESIGHT GAIN	-		39.0 DB	+2.0 DB -0.0 DB
0.5 PWR BEAMWIDTH	-		1.3°	-
SCAN ANGLE	-		15° CONICAL	MIN
SCAN LOSS	-		3.0 DB	+0.0 DB -3.0 DB
POINTING ACCURACY	-		0.2 BEAMWIDTH	MAX
POINTING LOSS	-		0.5 DB	+0.0 DB -0.5 DB
G. POLARIZATION	RCP		RCP	
LOSS	0.5 DB	+0.0 DB -0.5 DB	-	
H. PATH LOSS	189.8 DP	+0.0 DB -0.8 DB	-	
I. RCVE CIRCUIT LOSS	4.4 DB	+0.0 DB -1.0 DB	-	
J. PREAMP INPUT LEVEL	-121.2 DBM	+11.8 DB -0.0 DB	-	
K. PREAMP/CABLE <small>NET GAIN</small>	14.0 DB	+2.5 DB -0.0 DB	-	
L. RECEIVER INPUT LVL	-97.2 DBM	+14.3 DB -0.0 DB	-	
M. RCVE SYS NOISE FIGURE	5.8 DB	+0.0 DB -0.1 DB	-	
N. 1.2 RAD BACK-UP VOICE				
MODULATION LOSS	3.0 DB	-	-	
LIMITER SNR LOSS (IF)	1.1 DB	-	0	
O. C/N DENSITY RATIO	42.9 DB-Hz	+11.9 DB -0.0 DB	90.9 DB-Hz	+13.9 DB -0.0 DB
P. NOISE BANDWIDTH	(7.7 kHz) 38.8 DB	+0.0 DB -1.1 DB	54.0 DB	-
Q. RECEIVED SNR	4.1 DB	+13.0 DB -0.0 DB	26.9 DB	+13.9 DB -0.0 DB
R. REQ'D SNR (70% INTELL.)	4.3 DB	MIN	-	
S. MARGIN	-0.2 DB	+13.0 DB -0.0 DB	-	

### 3.4 USBE MODES

The remaining operating modes in Table 2-4 are ATS-R Tracking Modes and services identical to the present USBE-CSM capability. The ATS-R modes are discussed in sufficient detail in Section 9. The USBE modes have been defined identical to the present system.<sup>3.14</sup> Based on the total uplink and downlink carrier-to-noise density ratios calculated in Tables 3-2 and 3-3, the worst case operating margins for these modes are calculated in Tables 3-7 and 3-8. All service on these modes are calculated to have at least a 10 db margin for simultaneous worst case parameters. The USBE all service modes selected for use (UP MODE 6 and DOWN PM MODE 4) probably represent the worst case operating conditions as far as link marginality is concerned. It is therefore possible (if desired) to provide additional CAT Relay operating modes using different combinations of Up-Voice, Up-Data and PRN on the uplink or Crew Voice, 51.2 Kbps Data, and PRN on the downlink with adequate operating margins. The intermixing of ATS-R tones and USBE services in the same operating mode has not been considered.

Table 3-7. Margins For Uplink Services

UPLINK MODE	INFORMATION	IF C/N DENSITY RATIO DB-Hz	INDEX RADIANIS	MODULATION LOSS DB	MAX NOISE BANDWIDTH INTERFER. DB	PRN CODE INTERFER. DB	RECEIVED SNR DB *	REQUIRED SNR DB	MARGIN DB *
UP MODE 1	CARRIER	78.2 +10.0 - 0	-	-	32.6	-	45.6 +10 - 0	6	39.6 +10 - 0
UP MODE 2	CARRIER PRN		-	12.8 0.2	32.6 59.1	-	32.8 18.9	6 -	26.8 -
UP MODE 3	CARRIER VOICE		-	10.1 1.7	32.6 43.8	-	35.5 32.7	6 10	29.5 22.7
UP MODE 4	CARRIER UP-DATA		-	10.1 1.7	32.6 43.8	-	35.5 32.7	6 10	29.5 22.7
UP MODE 5	CARRIER VOICE		-	5.7 6.4	32.6 43.8	-	39.9 28.0	6 10	33.9 18.0
UP MODE 5	CARRIER UP-DATA		-	5.7 6.4	32.6 43.8	-	39.9 28.0	6 10	33.9 18.0
UP MODE 6	CARRIER VOICE UP-DATA PRN		-	4.8 6.6 9.5 10.0	32.6 43.8 43.8 59.1	- 1.7 1.7 -	40.8 26.1 23.2 9.1	6 10 10 -	34.8 16.1 13.2 -
UP MODE 7	CARRIER 5MHZ TONE LOW TONE		-	7.0 6.5 6.5	32.6 51.8 59.1	- - -	38.6 19.9 12.6	6 - -	32.6 - -
UP MODE 8	CARRIER 500KHZ TONE LOW TONE		-	7.0 6.5 6.5	32.6 59.1 59.1	- - -	38.6 12.6 12.6	6 - -	32.6 - -
UP MODE 9	CARRIER BU.VOICE	-	3.5 3.0	32.6 38.8	- -	42.1 36.7	6 4.3	36.1 32.4	

\* - 0 TOLERANCE APPLIES TO ALL ENTRIES IN THESE COLUMNS.

Table 3-8. Margins for Downlink Services

DOWNLINK MODE	INFORMATION	IF C/N DENSITY RATIO DB-Hz	INDEX RADIAN	MODULATION LOSS DB	MAX. NOISE BANDWIDTH DB †	MOD. LOSS (UPLK+NOISE) DB	RECEIVED SNR DB	REQUIRED SNR DB †	MARGIN DB
DOWN PM MODE 1	CARRIER	↑ 81.0 +8.9 - 0 ↓	-	-	29.2	-	51.8 +8.9 - 0	12	39.8 +8.9 - 0
DOWN PM MODE 2	CARRIER PRN		-	12.8	29.2	-	39.0 +8.9 - 0	12	27.0 +8.9 - 0
DOWN PM MODE 3	CARRIER		1.34	0.2	0	-	76.2 * - 0	32	44.2 * - 0
	CREW VOICE TLM DATA		-	4.6	29.2	-	47.2 +8.9 - 0	12	35.2 +8.9 - 0
DOWN PM MODE 4	CARRIER		0.7	10.1	46.8	-	24.1 +8.9 - 0	8	16.1 +8.9 - 0
	CREW VOICE		1.2	4.2	53.0	-	23.8 +8.9 - 0	8.5	15.3 +8.9 - 0
	TLM DATA		-	5.7	29.2	3.7	42.4 +8.9 - 0	12	30.4 +8.9 - 0
	PRN		0.7	11.2	46.8	3.7	19.3 +8.9 - 0	8	11.3 +8.9 - 0
DOWN PM MODE 5	CARRIER		1.2	5.3	53.0	3.7	19.0 +8.9 - 0	8.5	10.5 +8.9 - 0
	5 MHz TONE		0.5	11.0	0	3.7	64.2 * - 0	32	32.2 +8.9 - 0
	LOW TONE		-	7.0	29.2	0.1	44.7 +8.9 - 0	12	32.7 +8.9 - 0
DOWN PM MODE 6	CARRIER		1.2	6.5	7.2	0.1	62.6 * - 0	8	8
	500 kHz TONE	1.2	6.5	0	0.1	69.8 * - 0	8	8	
	LOW TONE	-	7.0	29.2	0.1	44.7 +8.9 - 0	12	32.7 +8.9 - 0	

† TAKEN FROM APPENDIX A OF "A PERFORMANCE ANALYSIS OF THE APOLLO UNIFIED S-BAND COMMUNICATIONS SYSTEM FOR A TYPICAL LUNAR MISSION", MSC-EB-R-67-1, ISD-MSC, MAY 1, 1967.

\* NOT CALCULATED, SEE SECTION 7 FOR FURTHER ANALYSIS.

‡ SEE SECTION 7 FOR ACCURACY ANALYSIS INVOLVING THESE PARAMETERS.

## REFERENCES

- 3.1 EIA Standard RS 170, November 1957
- 3.2 Merts, Fowler, and Christopher, Proceedings of the IRE, November 1950
- 3.3 Proceedings of the IRE, June 1960, Special Issue on TV
- 3.4 Performance Testing of TV Channels - Lenkurt Demodulator, October 1963
- 3.5 CCIR Volume, 1963
- 3.6 EIA Standard RS250A, February 1967
- 3.7 Transmission Systems for Communications, Bell Telephone Laboratories, 1964
- 3.8 CCIR Recommendation 421-1, Annex III, (Volume V)
- 3.9 R.A. Bruce - Transactions on Communication Techniques, September 1964
- 3.10 ATS-F Spacecraft Performance Requirements Specification for the Nimbus/AAP Data Relay Experiment, GSFC S-733-P-15, August 1968
- 3.11 Pickard, et al, The ATS-F Data Relay Experiment, Volume I
- 3.12 Laughlin and Heffernan, NASA Report X-733 68-190, May 1968
- 3.13 Apollo CSM P&I Specification, SID 64-1613, North American Aviation, Inc., August 15, 1966.
- 3.14 "A Performance Analysis of the Apollo Unified S-Band Communications System for a Typical Lunar Mission", MSC EB-R-67-1, ISD-MS, May 1, 1967

## SECTION IV

### 4. LABORATORY TEST PROGRAM

The transmission of real time television video (Down FM Modes 1 and 2) downlink is the most demanding CAT Relay operational mode from the standpoints of ERP, design analysis and evaluation and equipment performance. Therefore, the major program focus has been spent on the TV transmission link. In order to assist in this design, a laboratory simulation of available Motorola equipments was constructed early in this program with the following objectives:

1. Provide demonstration capability to document the feasibility of transmitting monochrome commercial format television picture signals simultaneous with crew voice from an Apollo Applications Cluster vehicle through a synchronous relay to a ground station using presently available space qualified equipment wherever possible.
2. Aid the completion of the Experiment system design by evaluating tradeoffs on an empirical operating basis.
3. Assemble test data for significant components of the final system design to provide information for an overall system specification as well as inputs for subsystem specifications.
4. Conduct statistical surveys on the value of the TV picture expected to be received at the ATS ground station as a function of SNR and signal predistortion.
5. Provide evaluation of the changes required to upgrade the recommended system for color TV transmission.

The laboratory simulation was purposely restricted to the capability to transmit and receive Down FM Modes 1 and 2 and did not include USBE format or ATSR signal processing. The results of the formal demonstrations and opinion surveys will be discussed in Section 10. This section will discuss the most significant test data extracted from the laboratory simulation system. A more complete report on the test results is given in reference 4. 1.

## 4.1 TEST SYSTEM

In order to get the most realistic data possible, the laboratory equipment was patterned after the actual CAT Relay Experiment recommended design (see Section 6) as far as is practical within the confines of the laboratory. Three notable exceptions were made, however, (1) no antennas were included, i. e., the r-f links were hard-wired with attenuators to simulate path loss, (2) the ATS-F relay repeater subsystem was simulated without frequency translation but including a diode limiter and bandpass filter and (3) provision was made for variation of practically all parameter variations to allow system optimization.

Figures 4-1 and 4-2 are simplified block diagrams of the two FM laboratory test systems. These systems are characterized by the use of the Motorola Wideband Telemetry Transmitter (Figure 4-1) and SGLS Transmitter (Figure 4-2), both of which are space qualified. A detailed block diagram of the composite laboratory test/demonstration equipment is recorded in Figure 4-3 and was oriented as shown in Figure 4-4. Details of the test units are covered in references 4.1 and 4.2 and the Wideband Telemetry Transmitter is discussed in Section 6.

The Motorola Quasar<sup>\*</sup> television sets were used to obtain live video programming in both monochrome and color for system evaluation. In addition, a CCTV system and monitors were used, all systems consisting of commercial 525 line, RS-170 video format (see Figure 3-1). The Motorola Wideband Receiver post detection bandwidth was set at 10 MHz for all tests and individual 3-pole, Butterworth-LPF switched in and out of the system for bandwidth control. A standard monochrome noise weighting network<sup>4.3</sup> and a standard pre-emphasis network<sup>4.4</sup> were used for all tests.

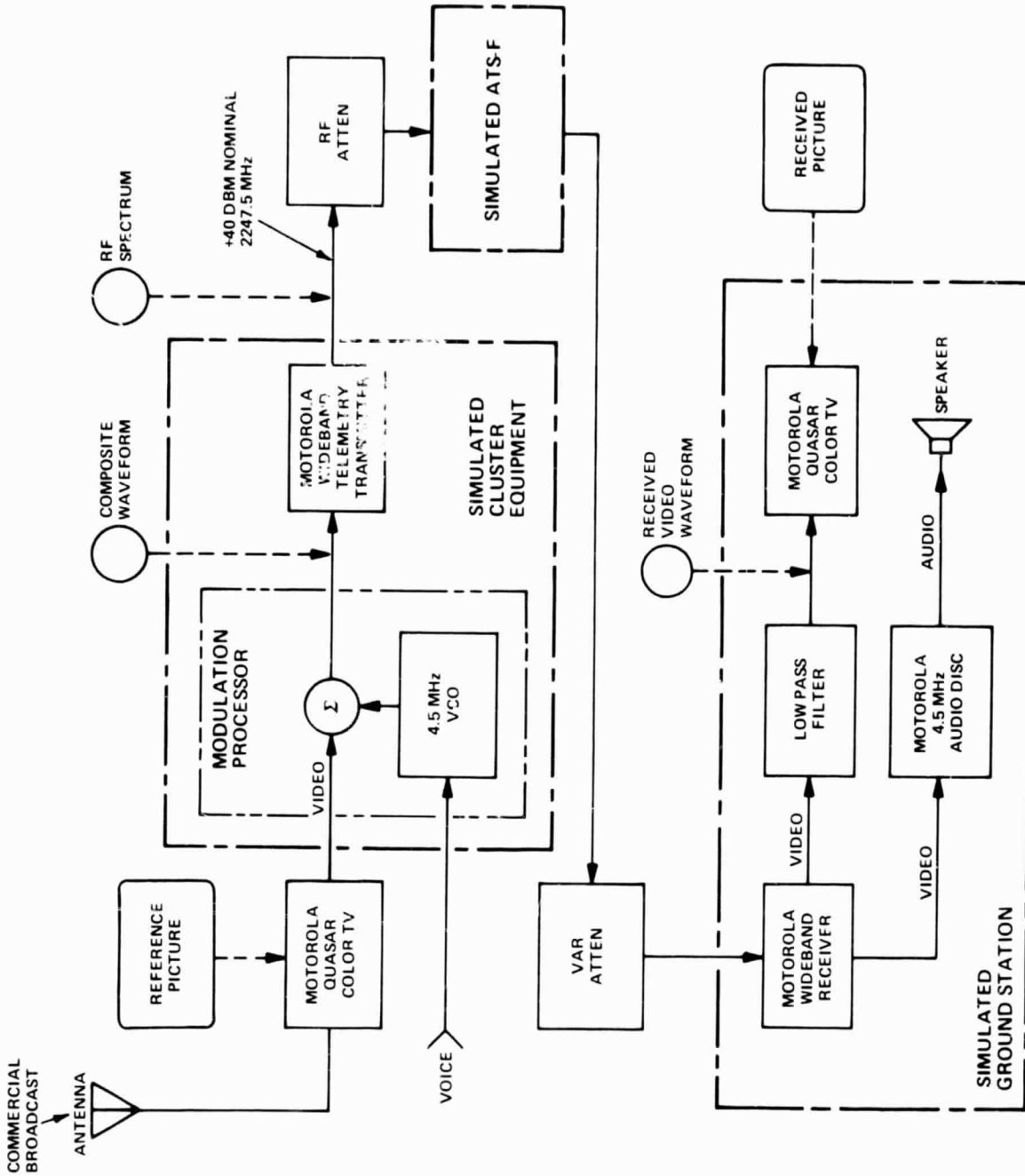
Two general characteristics of video systems were initially measured using just the CCTV vidicon camera fed directly into a monochrome monitor (800 line horizontal resolution) while transmitting the standard RETMA test pattern. Figure 4-5A shows the measured monochrome spectrum and Figure 4-5B the relationship between horizontal resolution of the TV picture and the baseband bandwidth of the video transmission system.

## 4.2 WIDEBAND TRANSMITTER SYSTEM TEST RESULTS

### 4.2.1 Measured Transfer Characteristics

The baseband to baseband frequency response of the Wideband Transmitter System (Figures 4-1 and 4-3) is reproduced as Figure 4-6. The

\* Registered trademark of Motorola, Inc.



SAFETY

Figure 4-1. Wideband Transmitter Laboratory FM TV/Voice Demonstration System

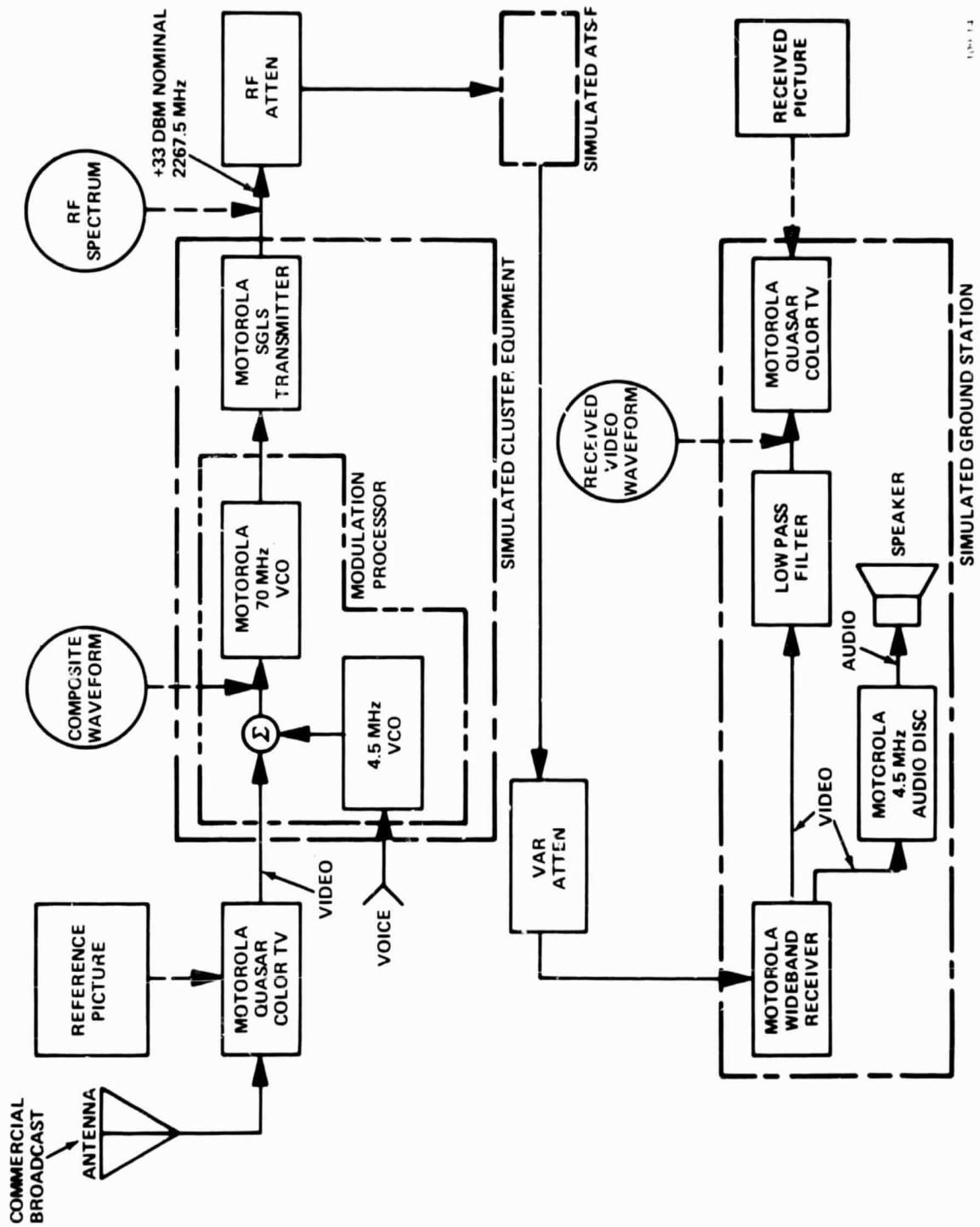
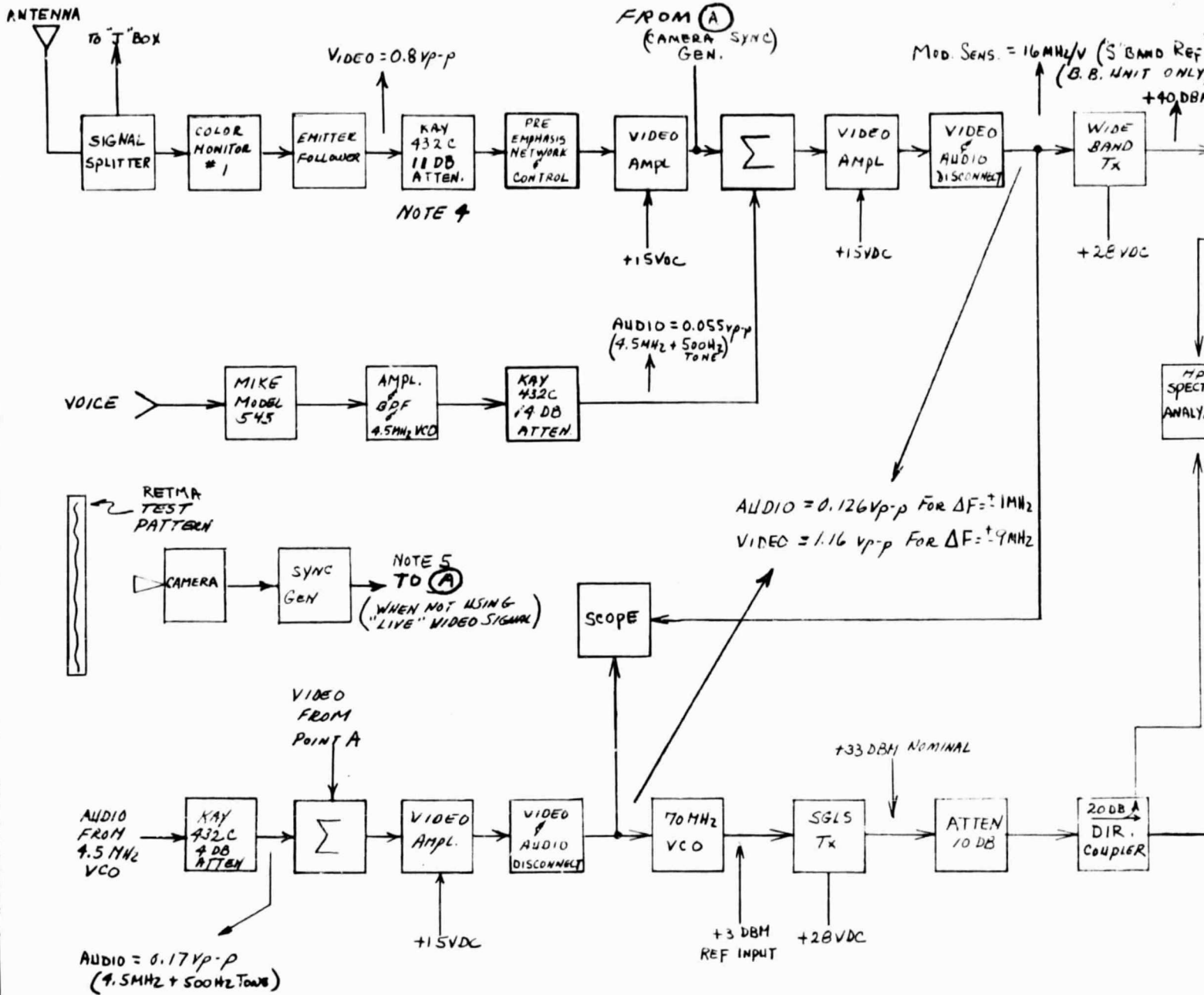


Figure 4-2. SGLS Transmitter Laboratory Demonstration System FM TV/Voice Relay

# COMMUNICATION AND TRACKING RELAY EXPER DOWNLINK FM TV / VOICE RELAY

FIGURE 4-3





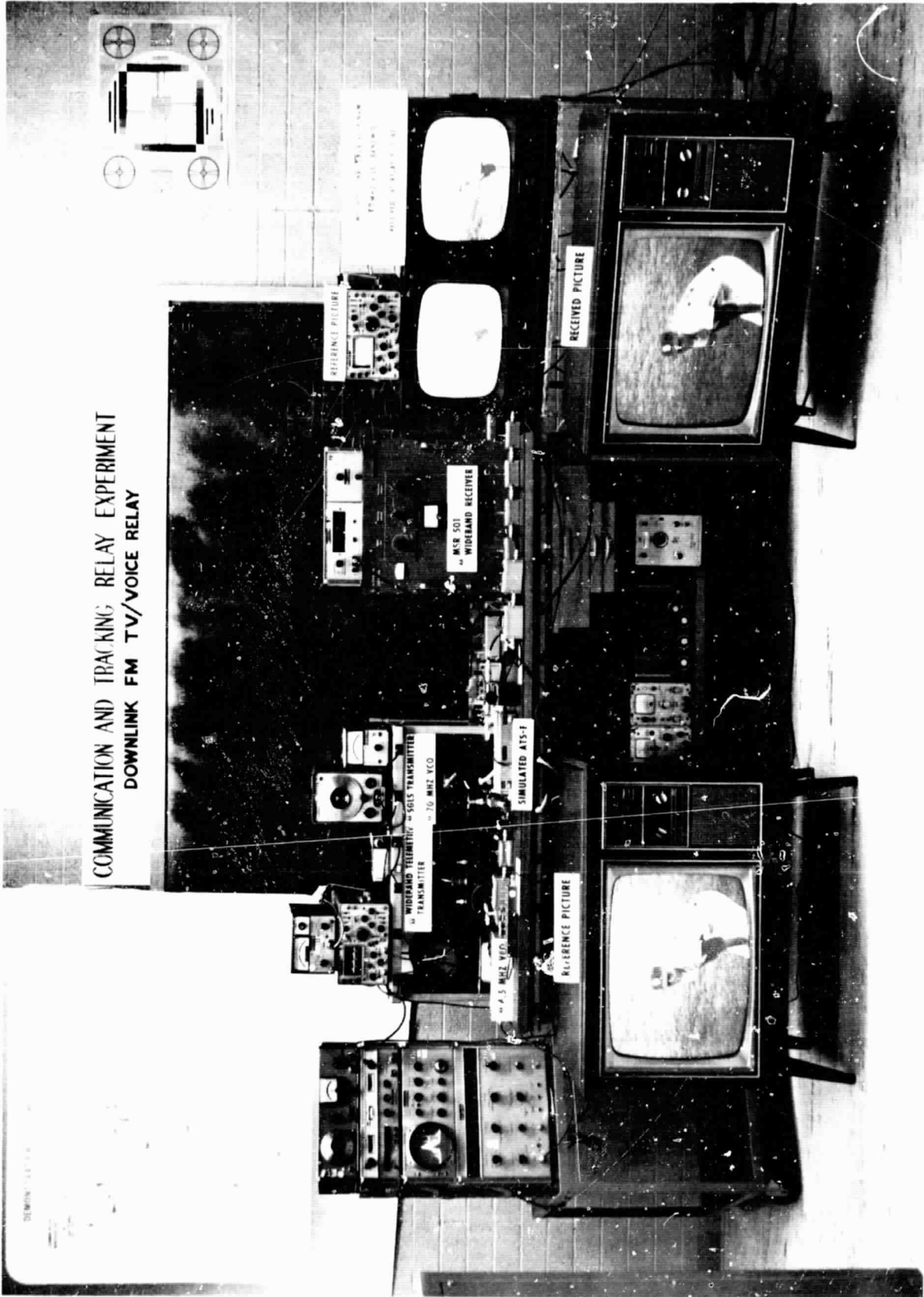
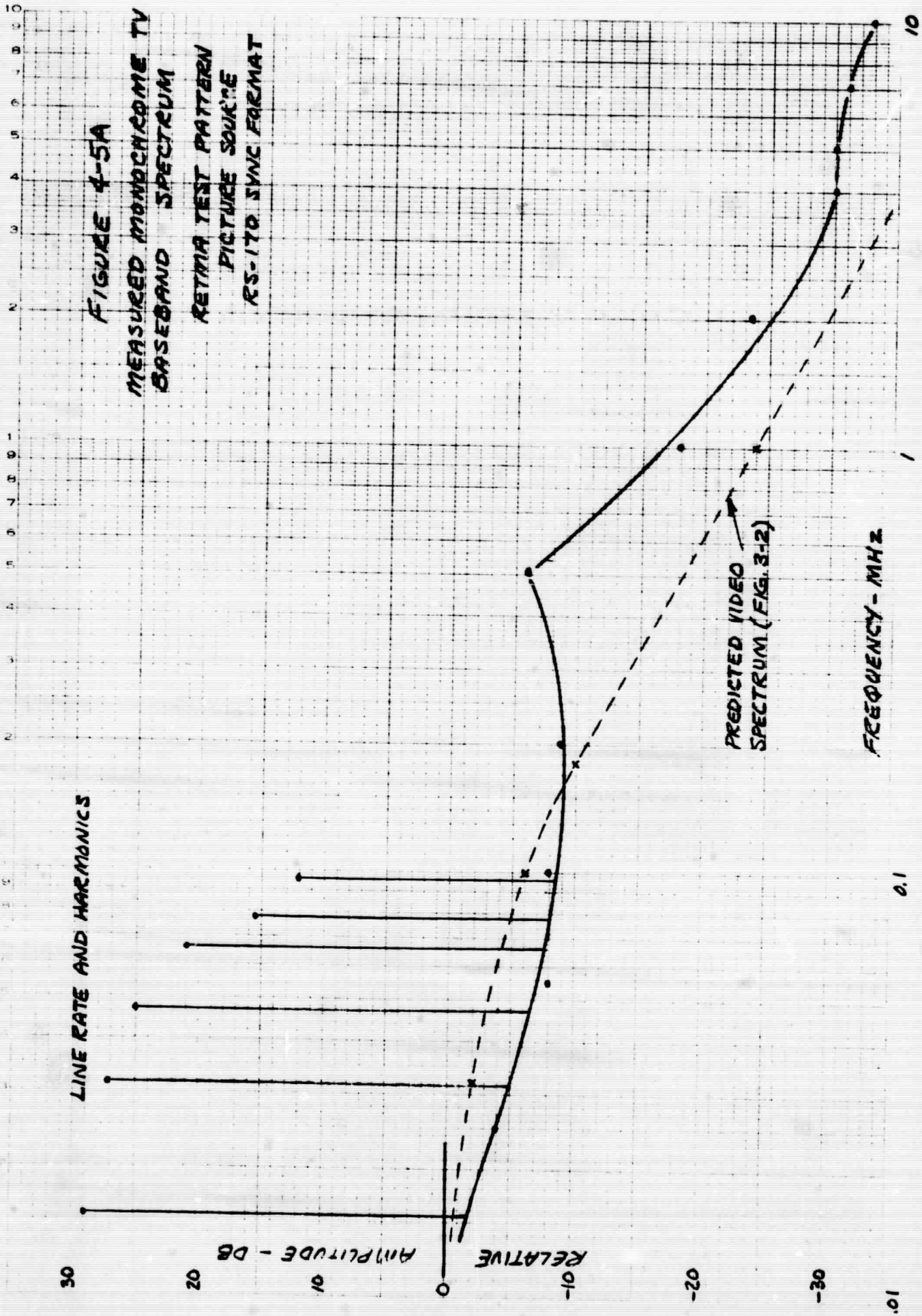


Figure 4-4. Simulated FM/TV Voice Relay Equipment

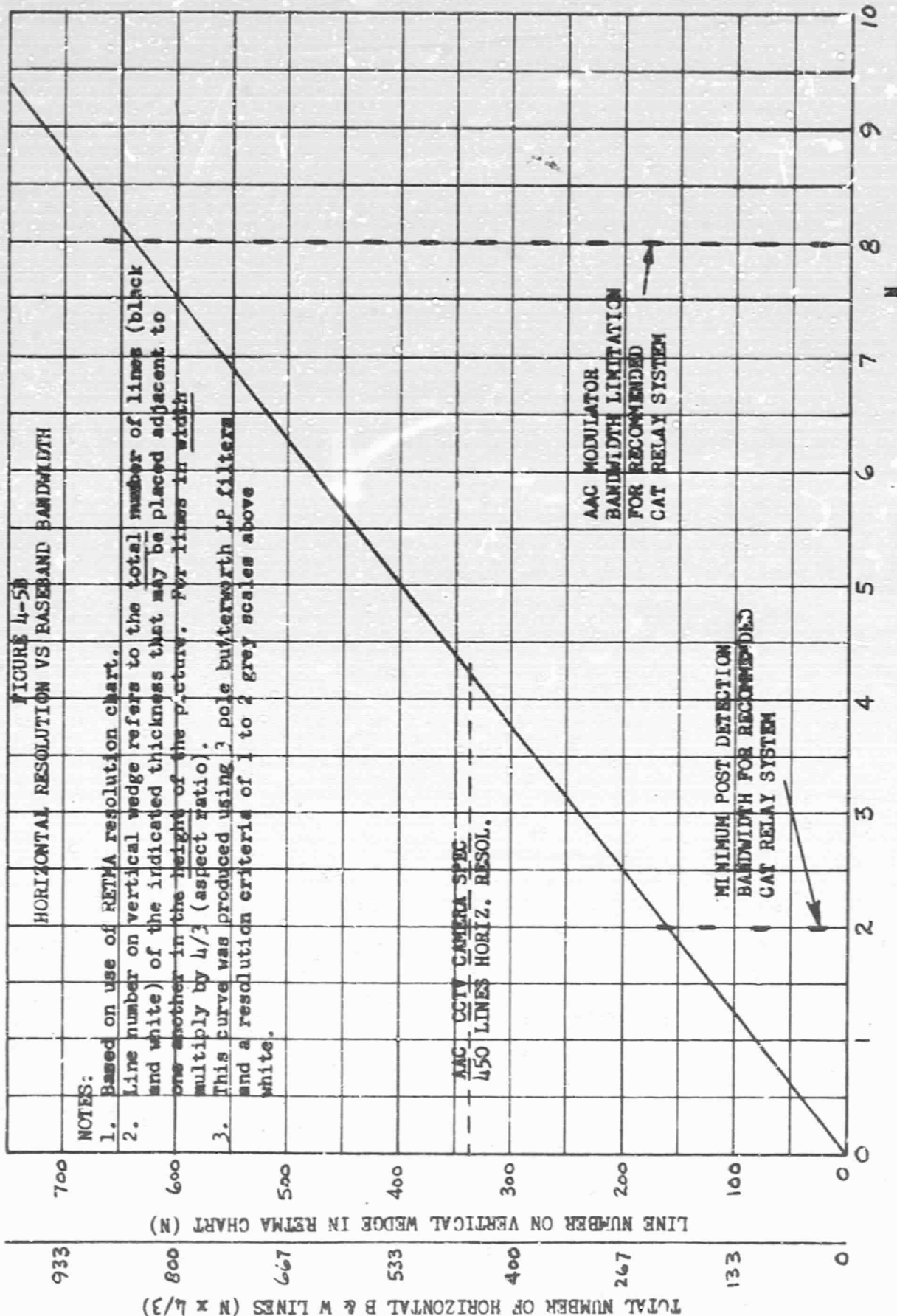


LINE RATE AND HARMONICS

FIGURE 4-5A  
 MEASURED MONOCHROME TV  
 BASEBAND SPECTRUM  
 RETINA TEST PATTERN  
 PICTURE SOURCE  
 RS-170 SYNC FORMAT

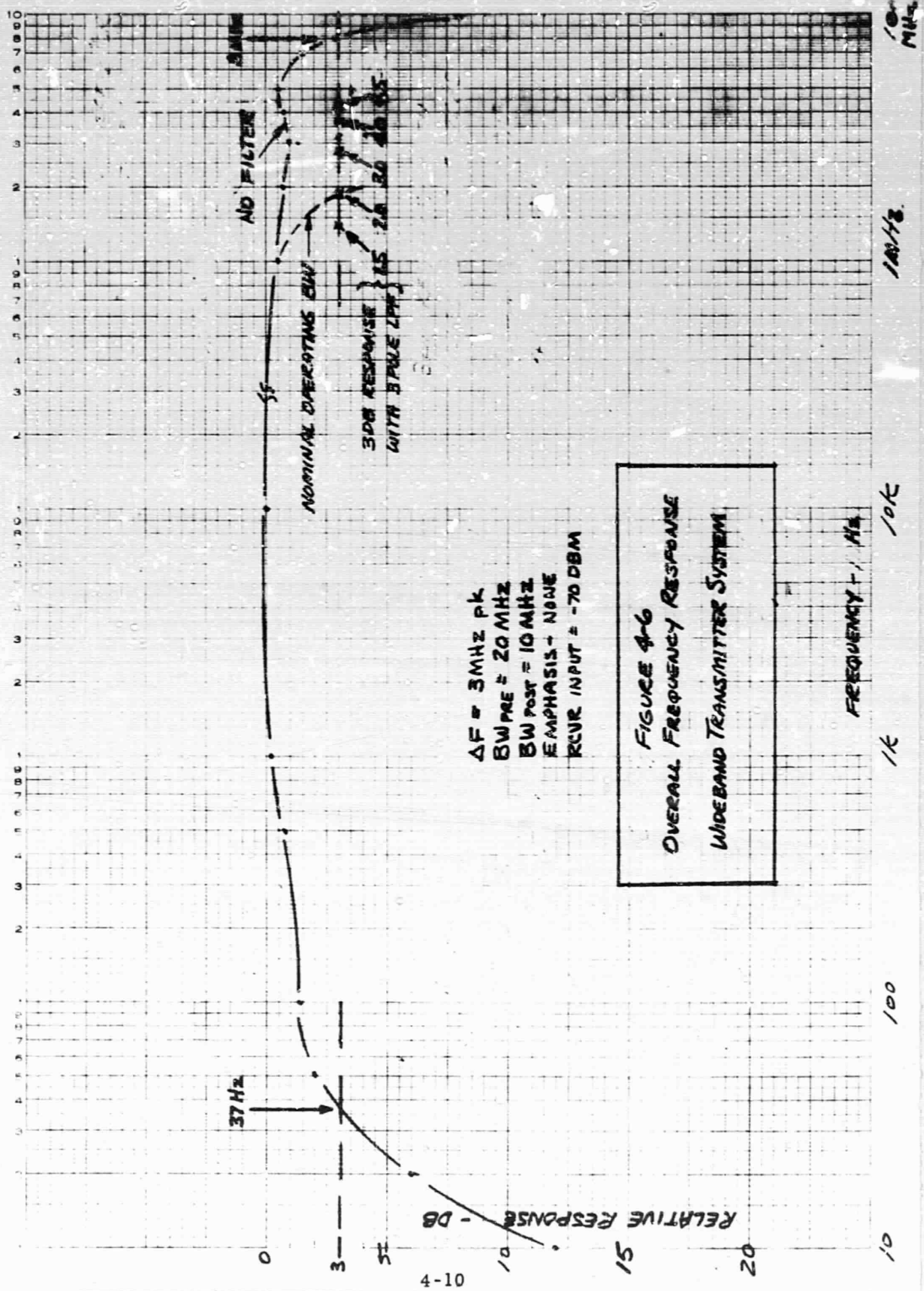
PREDICTED VIDEO  
 SPECTRUM (FIG. 3-2)

FREQUENCY - MHZ



FUNDAMENTAL FREQUENCY (F) DEVELOPED IN SCANNING A LINE (N) ( $F=50$ ), ALSO THE REQUIRED BASEBAND TRANSMISSION 3 DB BANDWIDTH - MHz

SEMI LOGARITHMIC  
5 CYCLES X 10 DIVISIONS PER INCH



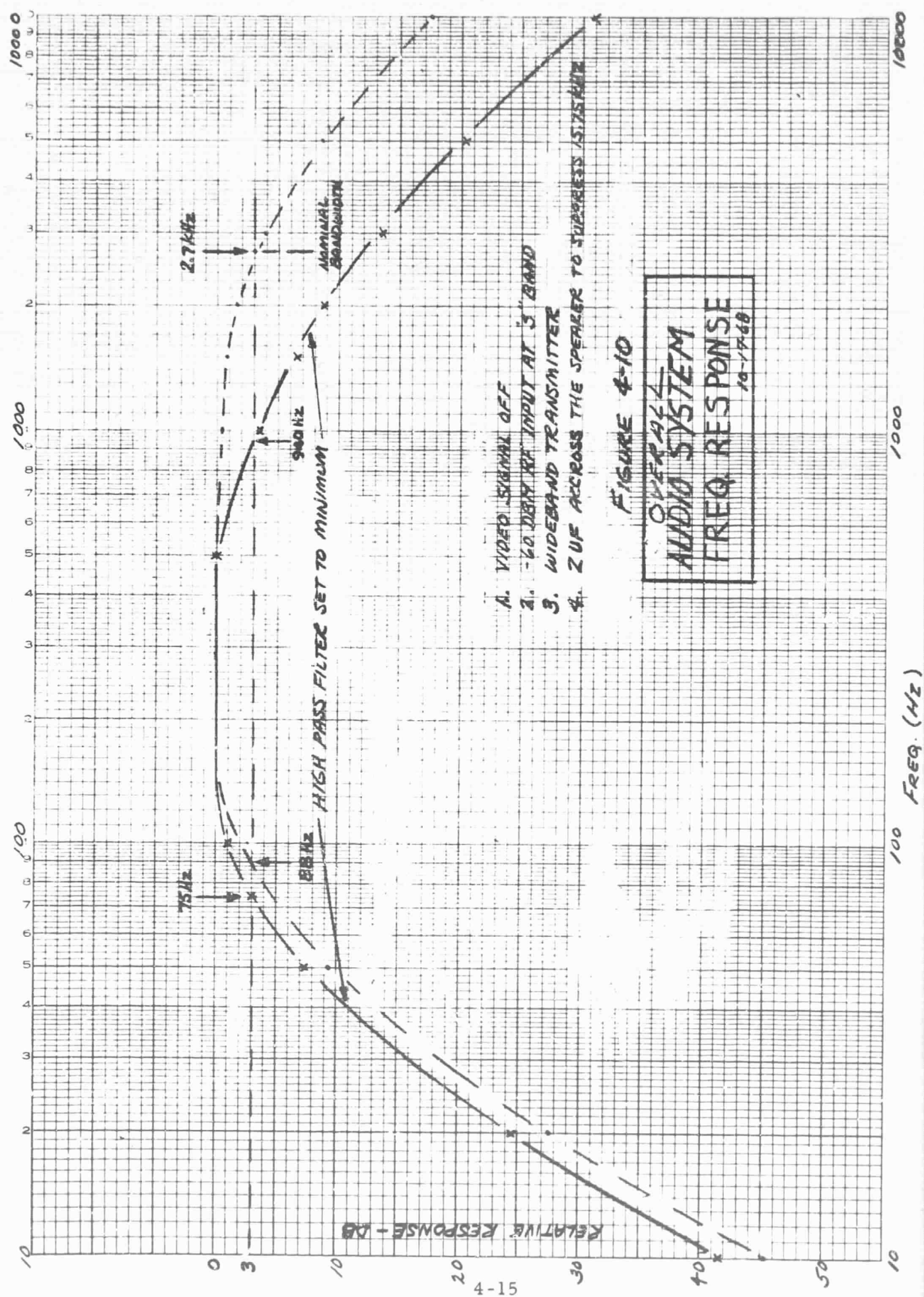
$\Delta F = 3 \text{ MHz PK}$   
 $BW_{PRE} = 20 \text{ MHz}$   
 $BW_{POST} = 10 \text{ MHz}$   
 EMPHASIS - NONE  
 REUR INPUT = -70 DBM

FIGURE 4-6  
 OVERALL FREQUENCY RESPONSE  
 WIDEBAND TRANSMITTER SYSTEM

frequency response is flat within 3 db from 37 Hz to 8 MHz. The high frequency cutoff points when using the separate 3-pole, LP-filters are also indicated.

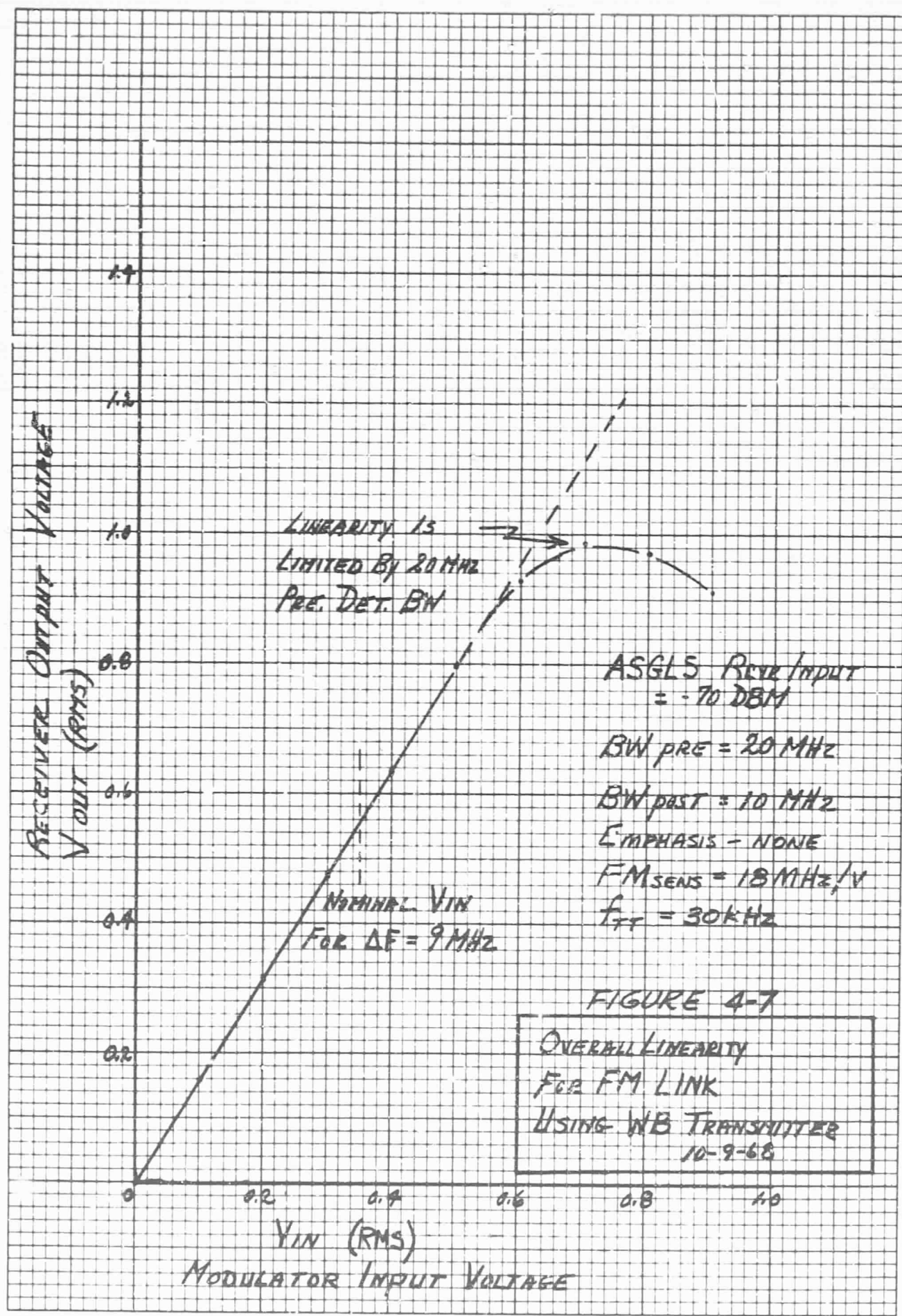
Several other system transfer functions were measured and are included in the following illustrations. System operating constants are listed on each and the worst case nominal operating point for the recommended system is labeled.

1. Figure 4-7. Voltage transfer function, modulator input to demodulated output.
2. Figure 4-8. Receiver threshold characteristic, i. e., post detection SNR as a function of predetection CNR. Mainly a function of the receiver threshold characteristic. Very close to theoretical calculated performance. Equivalent worst case operation is somewhat arbitrary since recommended system uses a threshold extension demodulator and 7 db CNR will be nominal worst case.
3. Figure 4-9. Post detection SNR improvement as a function of post detection (baseband) bandwidth. The observed results are not as spectacular as indicated because of the loss of horizontal resolution as the bandwidth is decreased (see Figures 4-5B and 4-17) thereby smearing picture under observation. The 15 db unweighted characteristic is very close to theoretical (9 db/octave slope) improvement.
4. Figure 4-10. Audio channel frequency response. Voice quality with 940 Hz bandwidth and decent SNR is very intelligible.
5. Figure 4-11. Subcarrier demodulator threshold characteristic. Approximate equivalent worst case operation is somewhat arbitrary since recommended system uses a threshold extension carrier demodulator and 100 kHz subcarrier predetection bandwidth. The measured data being 4 db below theoretical calculations has not been satisfactorily accounted for as yet, however, more than adequate voice link quality was obtained with the laboratory system. The measured 500 Hz tone distortion was 4.9% at 2.7 kHz post detection bandwidth.
6. Figure 4-12. The tradeoff of voice-video channel SNR for fixed video deviation is plotted. Actually 6.5 db voice SNR improvement could be obtained at the expense of about 1.5 db in video SNR.



- A. VIDEO SIGNAL OFF
- 1. -60 DB/DECADE INPUT AT 3" BAND
- 3. WIDEBAND TRANSMITTER
- 4. ZUF ACROSS THE SPEAKER TO SUPPRESS 15.75 KHZ

FIGURE 4-10



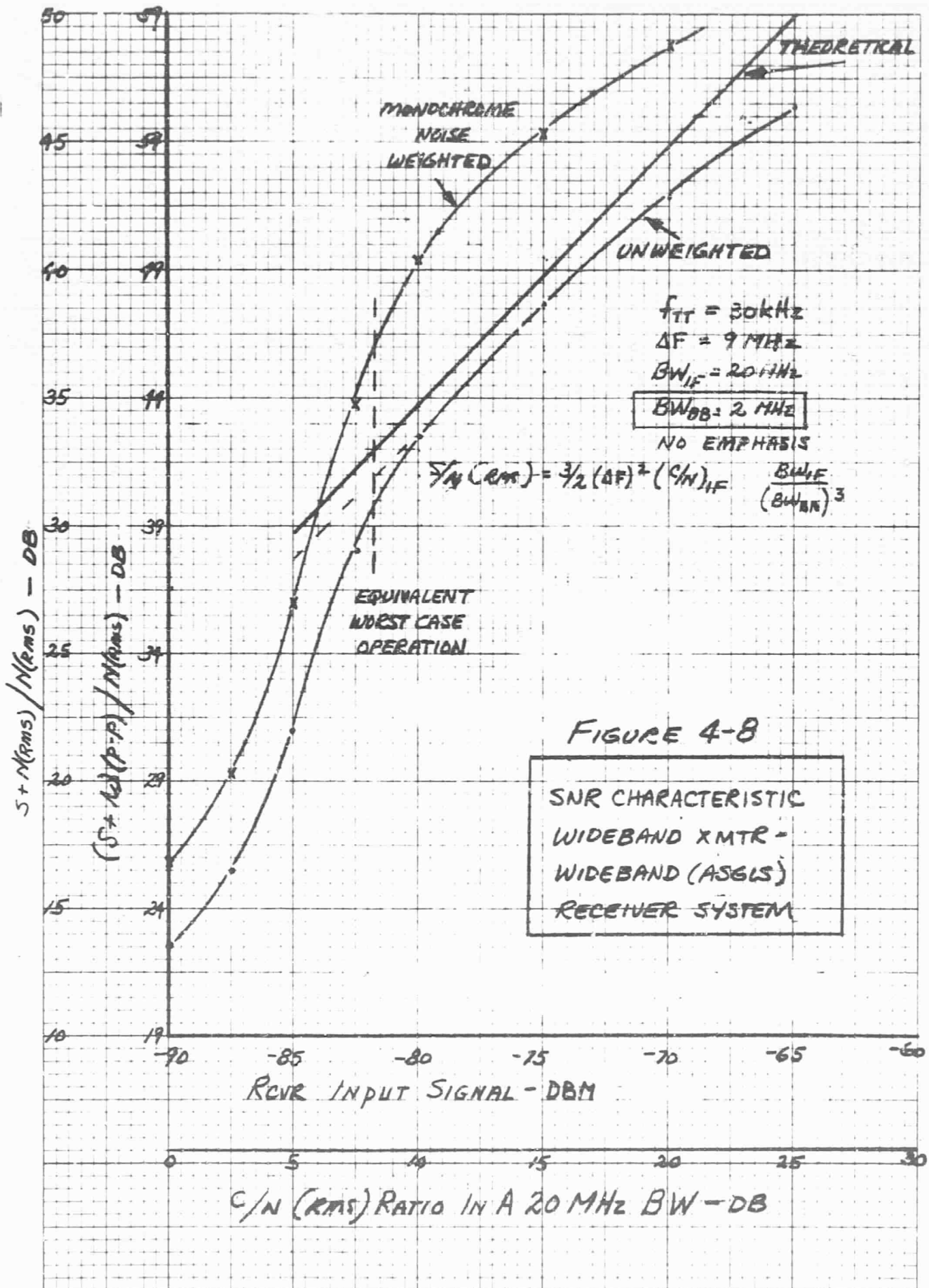
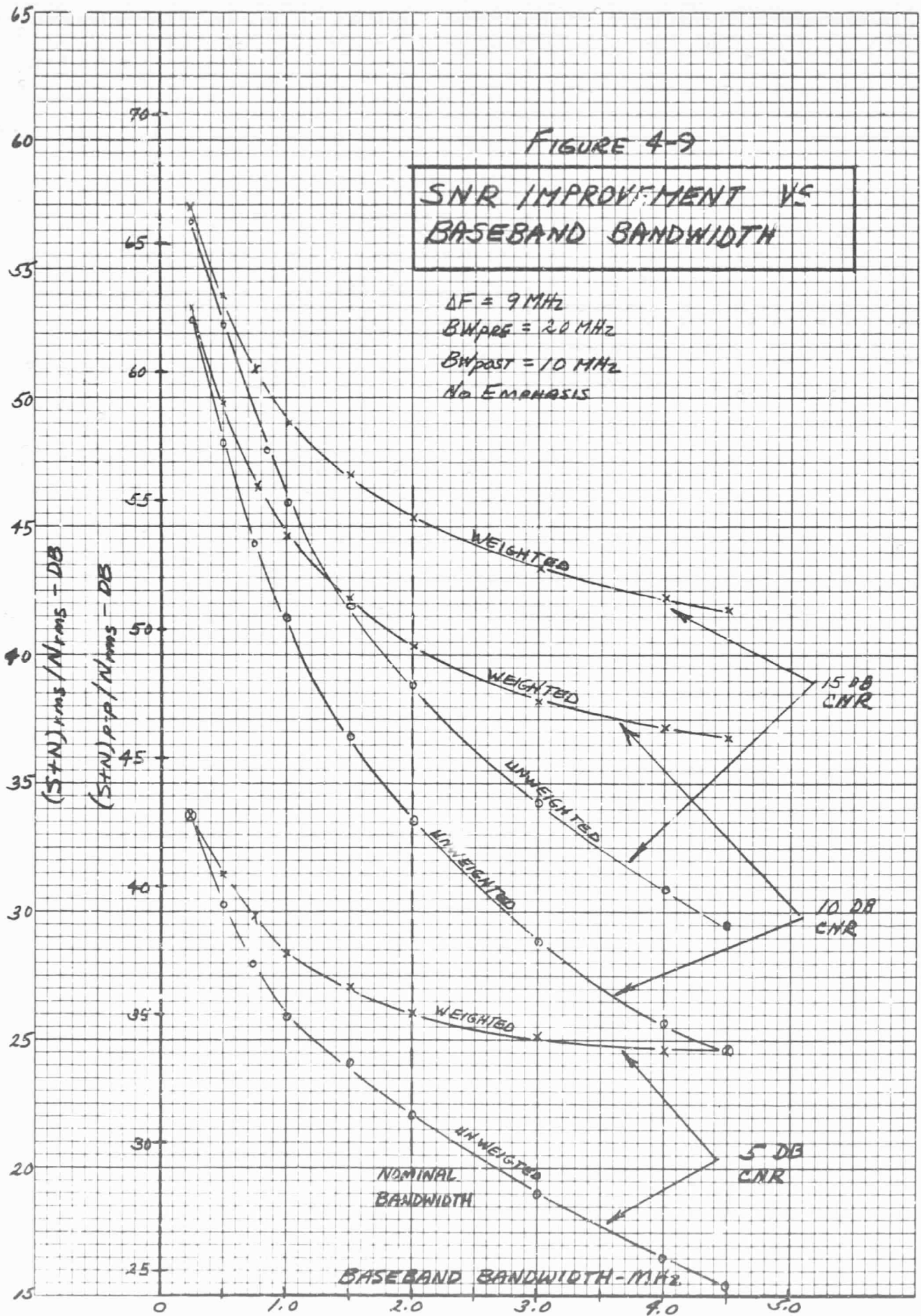
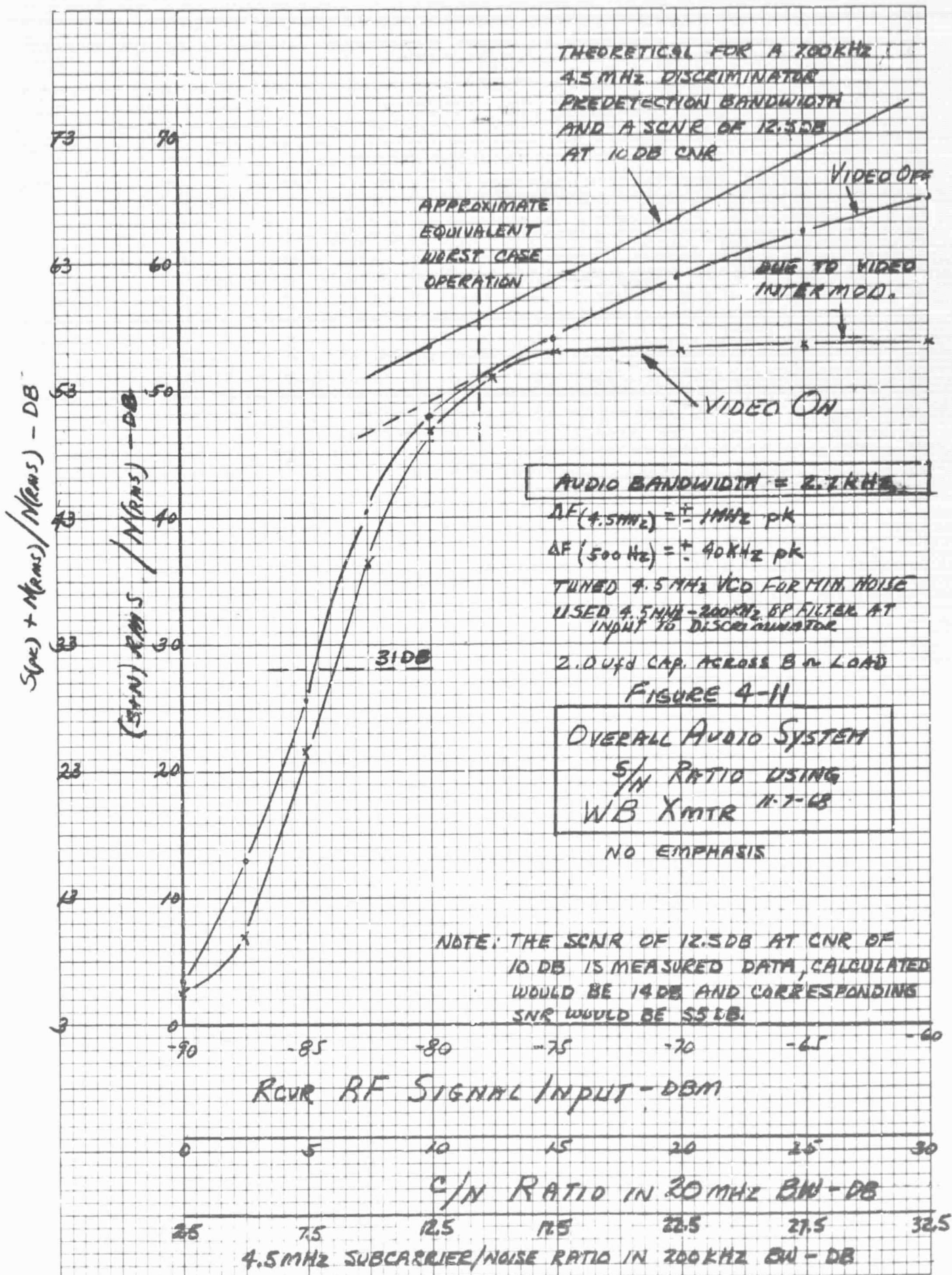


FIGURE 4-9  
**SNR IMPROVEMENT VS  
 BASEBAND BANDWIDTH**

$\Delta F = 9 \text{ MHz}$   
 $BW_{pre} = 20 \text{ MHz}$   
 $BW_{post} = 10 \text{ MHz}$   
 No EMphasis





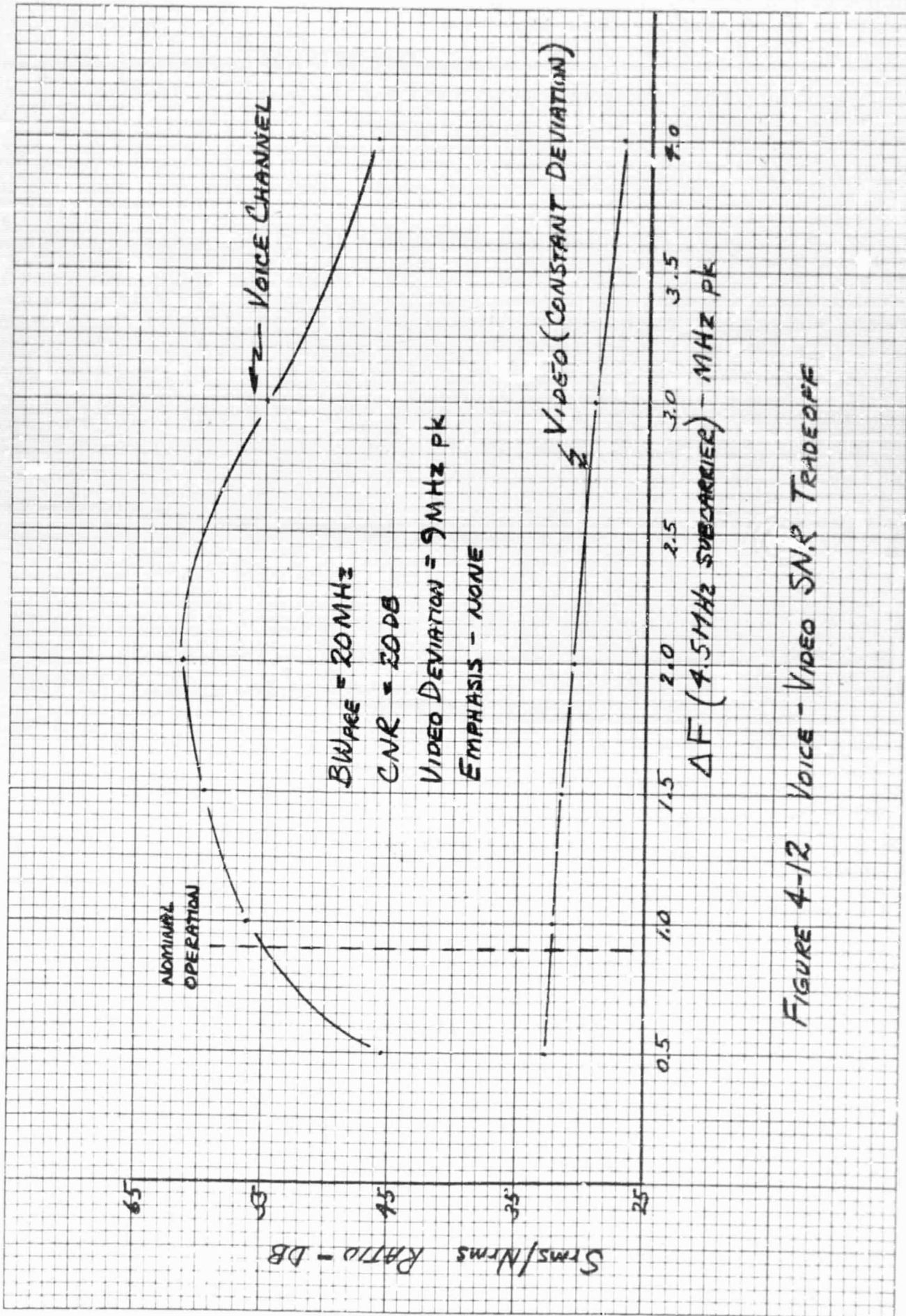


FIGURE 4-12 VOICE - VIDEO SNR TRADEOFF

#### 4. 2. 2 Measured Picture Quality

Photographs are presented in Figures 4-13 thru 4-16 which represent the received picture quality for 13 db to 4 db CNR demodulated in a standard 10 db threshold FM receiver. All photographs were taken with Polaroid type PN55 film at a speed of 1/10 second and shutter setting of f4. 7. Several observations are pertinent.

1. Experience has shown that the photographs appear less noisy than actual observed TV pictures due to film exposure time of more than one frame and therefore noise integration takes place.
2. The click noise present below FM threshold is significantly more objectionable than Gaussian noise above threshold for measured equivalent post detection SNR.
3. At 10 db CNR, noise just becomes perceptible in the picture and not objectionable, being very difficult to detect at reasonable viewing distances.
4. The recommended system will operate at 7 db CNR worst case with a threshold extension demodulator (6 db threshold). This is very nearly equivalent to the quality obtained on the laboratory system at 9 db CNR with a standard FM demodulator.

The results of picture quality surveys as related to these picture S/N ratios is given in paragraph 10. 2. With pre-emphasis/de-emphasis, only the video signal is emphasized. The transmitter deviation with pre-emphasis is set to the same rms deviation as the nonemphasized case. Although about 3 to 4 db improvement in SNR can be achieved with emphasis above threshold<sup>4, 5</sup>, the Motorola survey (Table 10-2) indicated mixed viewer reaction on its effectiveness both above and below threshold.

The effects of narrowbanding the post detection circuitry at strong signal is presented in Figure 4-17. One MHz video is still palatable, however 500 kHz TV is really objectional. The 2250 MHz modulated carrier spectrum with live TV programming and as a function of emphasis is recorded in Figure 4-18 for future reference. A relatively crude group delay distortion generator was assembled and used to evaluate tolerable distortion at rf for a monochrome FM link. In general, it was determined that 80 nanoseconds p-p (composite linear, parabolic and ripple distortions) additional link group delay distortion over the 20 MHz rf bandwidth would cause the horizontal sync pulses to phase invert and thus loss horizontal sync. This was the immediate and most pronounced picture degradation.

C/N = 13 db

$\Delta F_{\text{video}} = 9 \text{ MHz pk}$

$\Delta F_{\text{audio}} = 1 \text{ MHz pk}$

$BW_{\text{pre}} = 20 \text{ MHz}$

$BW_{\text{post}} = 2 \text{ MHz}$

No Pre-Emphasis



Figure 4-13

C/N = 13 db

$\Delta F_{\text{video}} = 3.92 \text{ MHz RMS}$

$\Delta F_{\text{audio}} = 1 \text{ MHz pk}$

$BW_{\text{pre}} = 20 \text{ MHz}$

$BW_{\text{post}} = 2 \text{ MHz}$

With Pre-Emphasis,  
De-Emphasis



C/N = 10 db

$\Delta F_{\text{video}} = 9 \text{ MHz pk}$

$\Delta F_{\text{audio}} = 1 \text{ MHz pk}$

$BW_{\text{pre}} = 20 \text{ MHz}$

$BW_{\text{post}} = 2 \text{ MHz}$

No Emphasis



Figure 4-14

C/N = 10 db

$\Delta F_{\text{video}} = 3.92 \text{ MHz RMS}$

$\Delta F_{\text{audio}} = 1 \text{ MHz pk}$

$BW_{\text{pre}} = 20 \text{ MHz}$

$BW_{\text{post}} = 2 \text{ MHz}$

With Pre-Emphasis,  
De-Emphasis



C/N = 7 db

$\Delta F_{\text{video}} = 9 \text{ MHz pk}$

$\Delta F_{\text{audio}} = 1 \text{ MHz pk}$

$BW_{\text{pre}} = 20 \text{ MHz}$

$BW_{\text{post}} = 2 \text{ MHz}$

No Pre-Emphasis



Figure 4-15

C/N = 7 db

$\Delta F_{\text{video}} = 3.92 \text{ MHz RMS}$

$\Delta F_{\text{audio}} = 1 \text{ MHz pk}$

$BW_{\text{pre}} = 20 \text{ MHz}$

$BW_{\text{post}} = 2 \text{ MHz}$

With Pre-Emphasis,  
De-Emphasis



C/N = 4 db

$\Delta F_{\text{video}} = 9 \text{ MHz pk}$

$\Delta F_{\text{audio}} = 1 \text{ MHz pk}$

BW<sub>pre</sub> = 20 MHz

BW<sub>post</sub> = 2 MHz

No Pre-Emphasis



Figure 4-16

C/N = 4 db

$\Delta F_{\text{video}} = 3.92 \text{ MHz RMS}$

$\Delta F_{\text{audio}} = 1 \text{ MHz pk}$

BW<sub>pre</sub> = 20 MHz

BW<sub>post</sub> = 2 MHz

With Pre-Emphasis,  
De-Emphasis



C/N = 20 db

$\Delta F_{\text{video}} = 9 \text{ MHz}$

$\Delta F_{\text{audio}} = 1 \text{ MHz}$

$BW_{\text{pre}} = 20 \text{ MHz}$

$BW_{\text{post}} = 1 \text{ MHz}$

No Pre-Emphasis



Figure 4-17

NARROW BAND POST DETECTION EFFECTS

C/N = 2 db

$\Delta F_{\text{video}} = 9 \text{ MHz}$

$\Delta F_{\text{audio}} = 1 \text{ MHz}$

$BW_{\text{pre}} = 20 \text{ MHz}$

$BW_{\text{post}} = 0.5 \text{ MHz}$

No Pre-Emphasis



$\Delta F_{\text{video}} = 9 \text{ MHz pk}$

$\Delta F_{\text{audio}} = 1 \text{ MHz pk}$

No Pre-Emphasis

Spectrum Width = 10 MHz/CM

2247.5 MHz

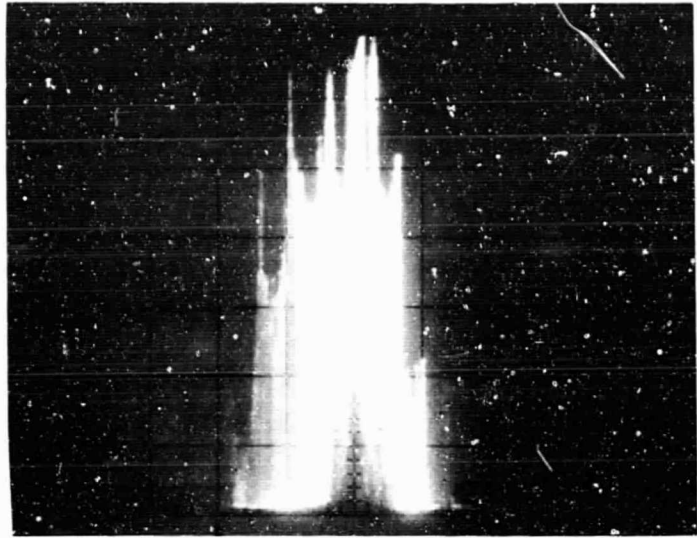


Figure 4-18

TYPICAL S-BAND FM SPECTRUM

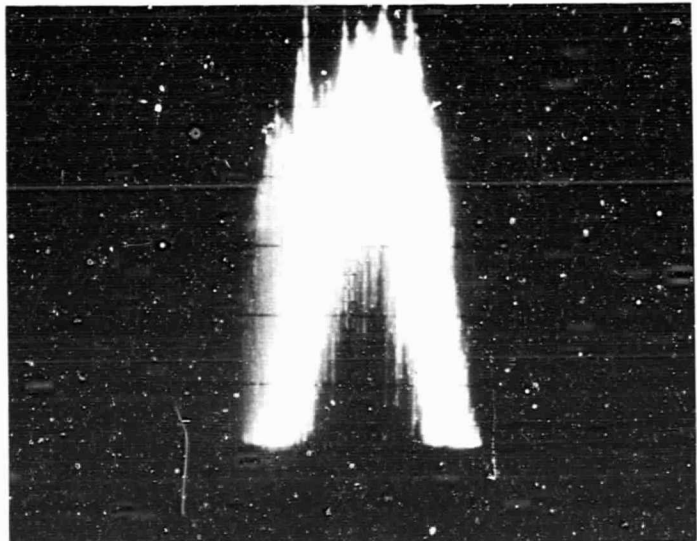
$\Delta F_{\text{video}} = 3.92 \text{ MHz RMS}$

$\Delta F_{\text{audio}} = 1 \text{ MHz pk}$

With Pre-Emphasis

Spectrum Width = 10 MHz/CM

2247.5 MHz



#### 4. 2. 3 Wideband Transmitter System Summary

The demonstrated system design parameters as listed in Table 4-1 definitely provide an acceptable quality experimental TV and voice transmission link based on observation during this program. Operation with the alternate design parameters utilizing a threshold extension demodulator (not demonstratable on this program) should provide only slightly inferior picture quality because the operating point is still above the receiver threshold. The following recommendations are also considered pertinent to the final Relay Experiment Configuration.

1. The TV picture still contains significant technical value at up to 6 db (CNR) below receiver threshold. The voice link is still intelligible at this level also with 1 kHz bandwidth. This provides a significant level of "last resort" margin in the system.
2. The use of emphasis should be made crew selectable at the transmitting and ground station terminals for further experiment evaluation.
3. Provisions for selectable video and voice post detection bandwidths should be made available at the ground station for user evaluation purposes during the Experiment. This will allow optimum link reception if the received CNR drops below the design limit due to unexpected degradation after launch.
4. Predetection bandwidths of 20 MHz and 30 MHz should be made available at the ground station for user evaluation purposes during the Experiment. The 30 MHz option will allow elimination of channel limiting or overloading which has been seen infrequently on extremely bright objects when emphasis is used.
5. Since relatively roisy video signals may have to be detected, a sync stripper regeneration and dc restorer unit is recommended for the ground station to clean up the sync even though the video is noisy. A snowy picture can be explained and accounted for, however, a rolling, snowy picture is of no value.

#### 4. 3 SGLS TRANSMITTER SYSTEM TEST RESULTS

Nearly all of the characterizations of TV picture quality made with the Wideband Transmitter system are applicable to this system. SGLS Transmitter system transfer characteristics are significantly different, however, and were measured separately (Figure 4-2 and 4-3 equipment).

Table 4-1. CAT Relay TV/Audio Link Operating Parameters

Carrier Link

Carrier Frequency	2253 MHz
Frequency Stability	$\pm 0.010\%$ maximum
Bandwidth Frequency Response (Overall)	-3 db maximum at 40 Hz $\pm 1$ db maximum, 100 Hz to 1 MHz -3 db maximum at 2 MHz Monotonic fall off above 2 MHz Optional 4 MHz (3 db) bandwidth
RF Noise Bandwidth	20 $\pm 0.5$ MHz (3 db)
Peak Frequency Deviation (Video and Subcarrier)	$\pm 9.9$ MHz minimum
Deviation Linearity	10% p-p maximum at $\pm 10$ MHz deviation
Received CNR at Demodulator	10 db design goal minimum in rf noise bandwidth for 50% of transmission 7 db worst case minimum (TED in ground station)
Envelope Delay Distortion	100 nsec p-p maximum in rf noise bandwidth with no discontinuities $\pm 50$ nsec maximum over 20 Hz to 2 MHz baseband
Pre-emphasis	Optional, 3.92 MHz RMS video deviation with pre-emphasis

Audio Subcarrier

Frequency	4.5 MHz
Frequency Stability	$\pm 0.2\%$ maximum
Baseband Frequency Response (Overall)	-3 db maximum, 50 Hz to 1.8 kHz
RF Noise Bandwidth	100 kHz minimum (3 db)
Peak Frequency Deviation	$\pm 45$ kHz minimum
Deviation Linearity	5% p-p maximum at $\pm 45$ kHz deviation

Table 4-1. CAT Relay TV/Audio Link Operating Parameters (cont)

Carrier Deviation	<u>+900</u> kHz
CNR at Demodulator	10 db maximum in rf noise bandwidth
Pre-emphasis	Not required
<u>Television System</u>	
Chrominance	Monochrome
Vertical Rate	60 Hz
Horizontal Rate	15.75 kHz
Scanning	2:1 positive interlace, 525 lines per frame
Synchronization Signal Waveform	EIA Standard RS-170
Aspect Ratio	4:3
Resolution	212 lines horizontal (2 MHz post detection bandwidth) 425 lines horizontal (4 MHz post detection bandwidth)
Weighted SNR (p-p/rms) at ground station	50.5 db at 10 db CNR goal, 2 MHz post detection bandwidth 47.5 db at 7 db CNR with TED, 2 MHz post detection bandwidth

1. Figure 4-19. Overall frequency response. Low frequency response anomaly was not investigated. Sound subcarrier has to be increased 10 db to get Wideband system equivalent performance. Modulation bandwidth is much narrower.
2. Figure 4-20. System voltage Transfer function. Less linear with overload than Wideband system.
3. Figure 4-21. Voice channel post detection SNR characteristic. Inferior to Wideband system.

It should be sufficient to say that even though the SGLS transmitter with an external 70 MHz FM modulator does a very adequate job in transmitting monochrome TV, the deficiencies relative to the Wideband Transmitter far outweigh any advantages. The disadvantages for use in the CAT Relay Experiment can be listed as follows:

1. Requires expensive TWT Amplifier to obtain equivalent or excessive rf power.
2. Stable, high-deviation, frequency modulator (about 70.5 MHz center frequency) is not available as a qualified existing design.
3. Narrower premodulation bandwidth precludes potential updating for color transmission and presently makes additional amplification of the voice subcarrier (4.5 MHz) necessary.
4. ATSR 5 MHz side tone unbalance is greater than 560 MHz phase modulator to be used with Wideband Transmitter. This causes appreciable range rate error (see paragraph 9.1.1.2). 5 MHz tone also must be amplified prior to modulation on the downlink.

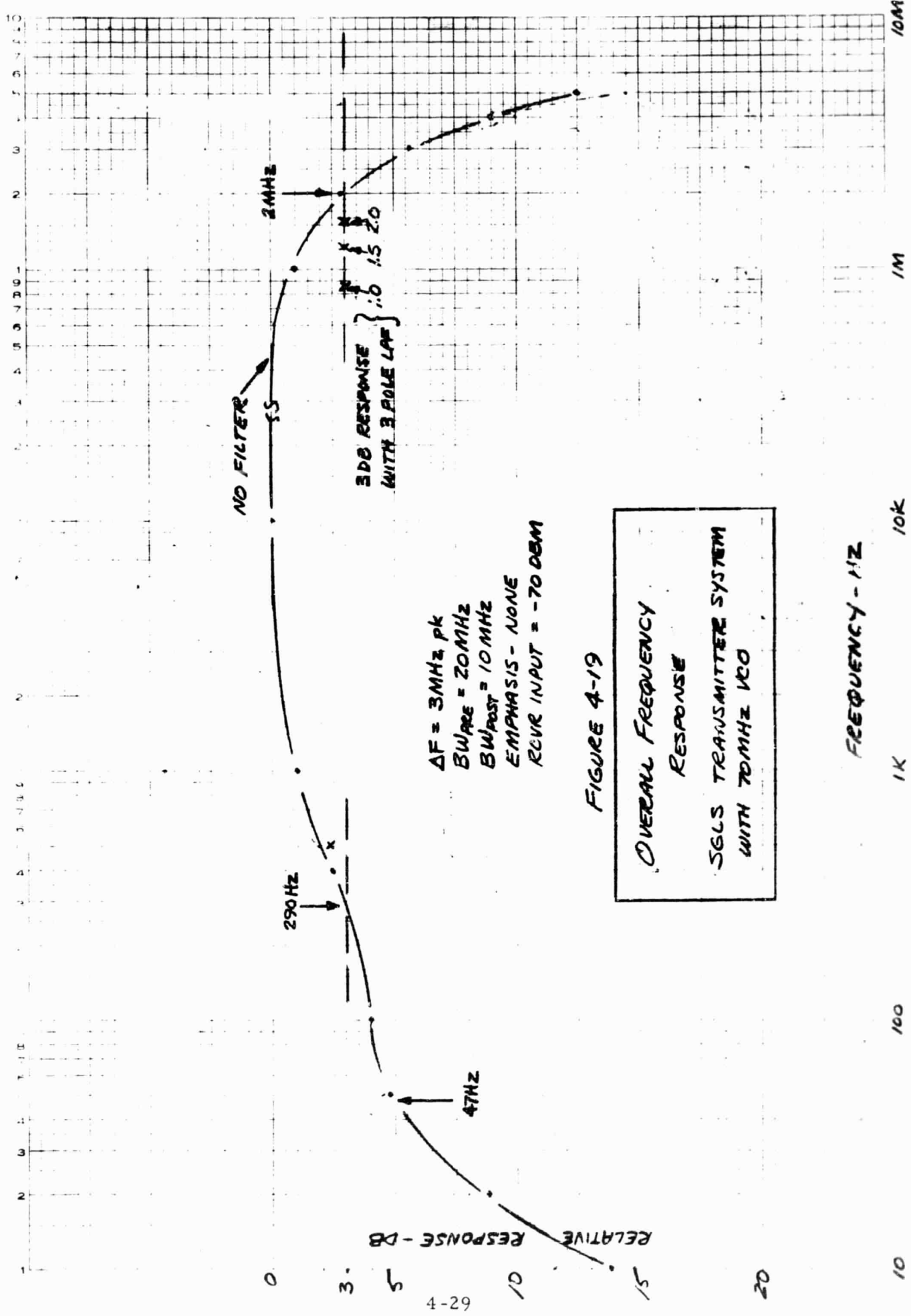
The SGLS Transmitter was originally considered when it appeared that 4 watts might be adequate for the TV link or for the back-up voice mode through the omni antennas. Since both of these suppositions have proven false, the SGLS Transmitter has been abandoned for consideration on the CAT Relay Experiment.

#### 4.4 TRANSMISSION OF COLOR TELEVISION

Sufficient interest was expressed in upgrading the recommended CAT Relay FM link for color transmission that an evaluation was performed with the Wideband Transmitter laboratory test system. In summary, the following changes to the recommended system would be required.

EUGENE DIETZGEN CO.  
MADE IN U.S.A.

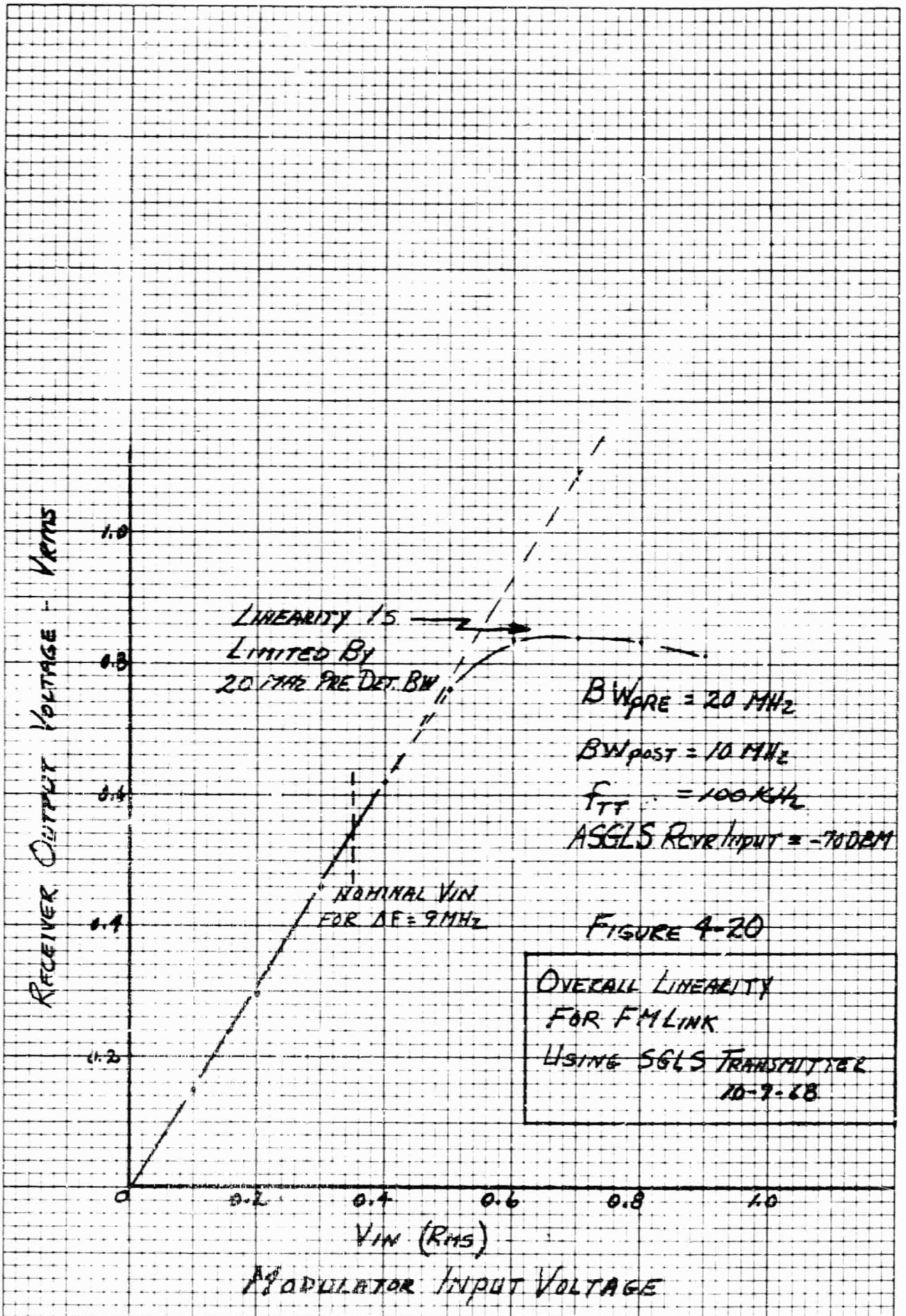
NO. 34 510 DIETZGEN GRAPH PAPER  
SEMI-LOGARITHMIC  
5 CYCLES X 5 DIVISIONS

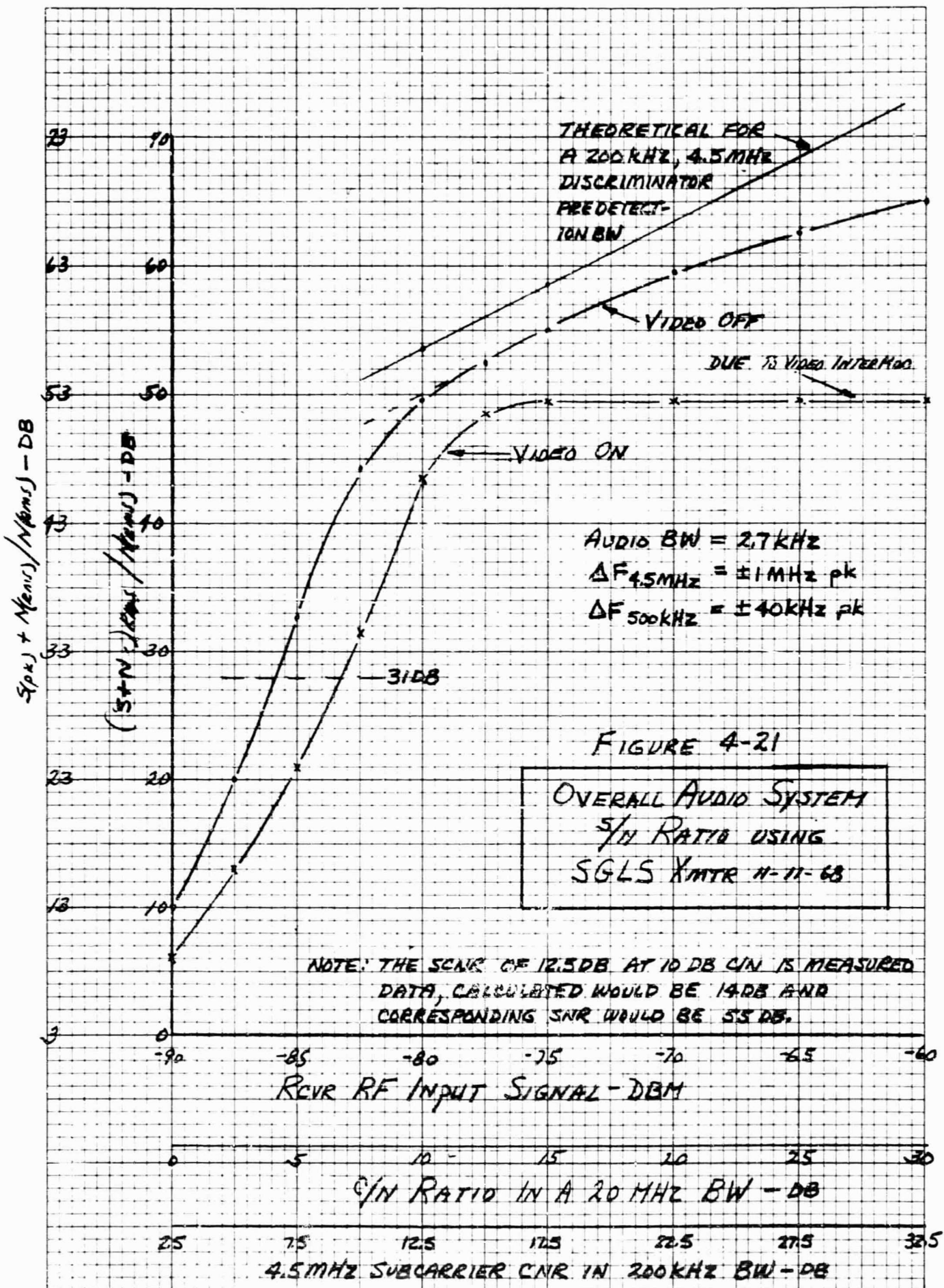


OVERALL FREQUENCY RESPONSE  
SGLS TRANSMITTER SYSTEM  
WITH 70 MHz VCO

FIGURE 4-19

$\Delta F = 3 \text{ MHz pk}$   
 $BW_{PRE} = 20 \text{ MHz}$   
 $BW_{POST} = 10 \text{ MHz}$   
 EMPHASIS - NONE  
 RCVR INPUT = -70 DBM



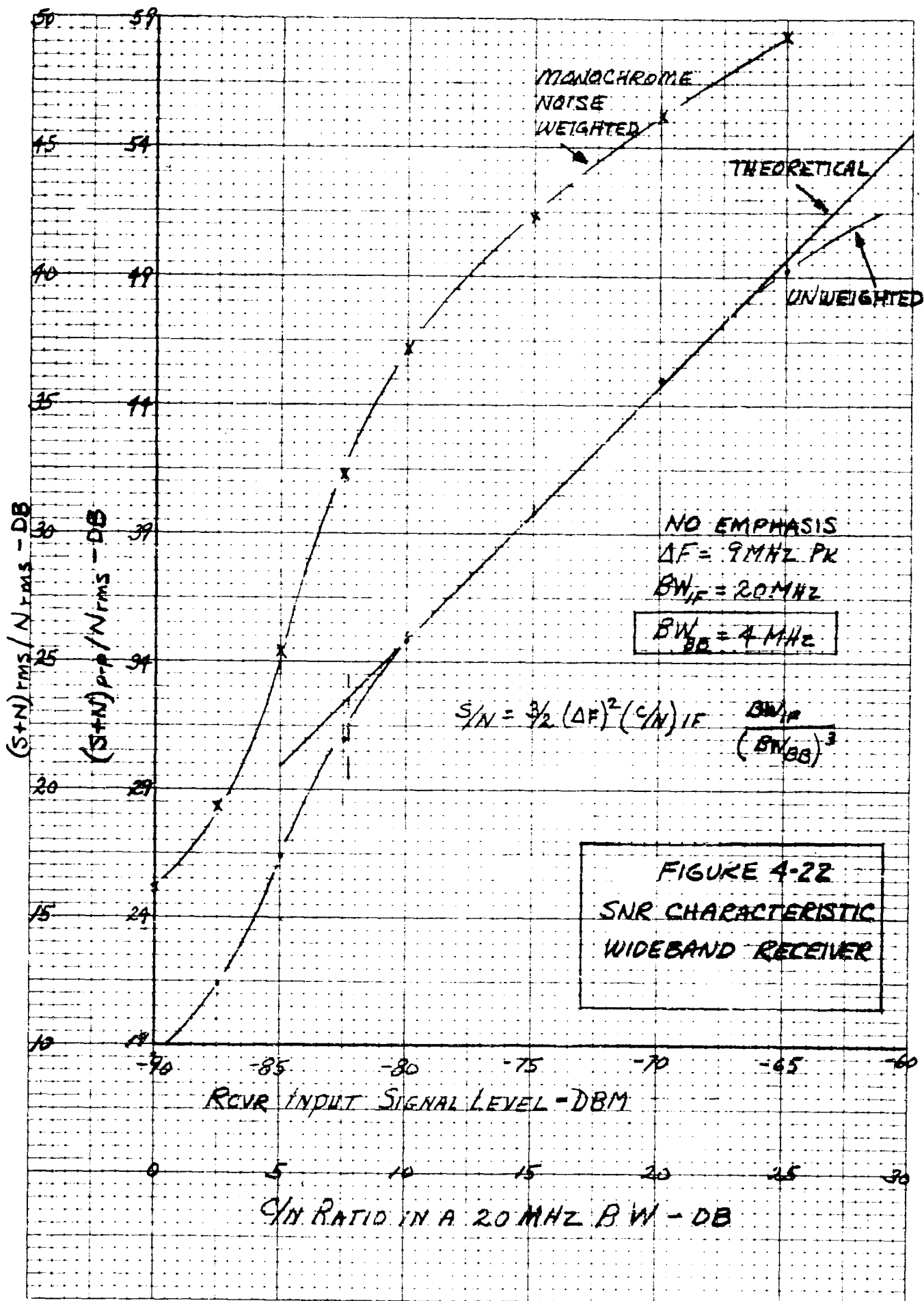


1. Increase the post detection bandwidth to 4 MHz to pass the video color information (approximately 1.5 to 4.5 MHz in the baseband spectrum).
2. Increase the composite downlink received C/N density ratio to 86 db-Hz for an acceptable quality color link with a standard 9 db threshold FM demodulator or to 89 db-Hz for an excellent quality link. No estimate is made for the threshold extension demodulator case.
3. Operate the link with pre-emphasis/de-emphasis circuits all the time.
4. Impose differential gain and phase specifications on the link compatible with commercial microwave relay links. The performance of the demonstration link in these areas is considered to be totally adequate, however, the additionally required unit (i. e. TWT, ATS-F, etc.) distortions are not accounted for.
5. Restrict the total link group delay distortion budget to not more than 10 nanoseconds p-p composite distortion at r-f over the 20 MHz bandwidth. This requirement is additional above the demonstration link performance for an excellent quality color link or 20 nanoseconds p-p additional for an acceptable quality color link.
6. Provide additional 4.5 MHz subcarrier rejection in the output video circuits to prevent cross modulation with the 3.58 MHz color subcarrier in the video.

In actual practice, these changes represent minimal additional restrictions to be added for the potential benefits to be gained. The most severe requirements would be increasing the link margin by the 3 to 6 db required and obtaining the low group delay distortion performance.

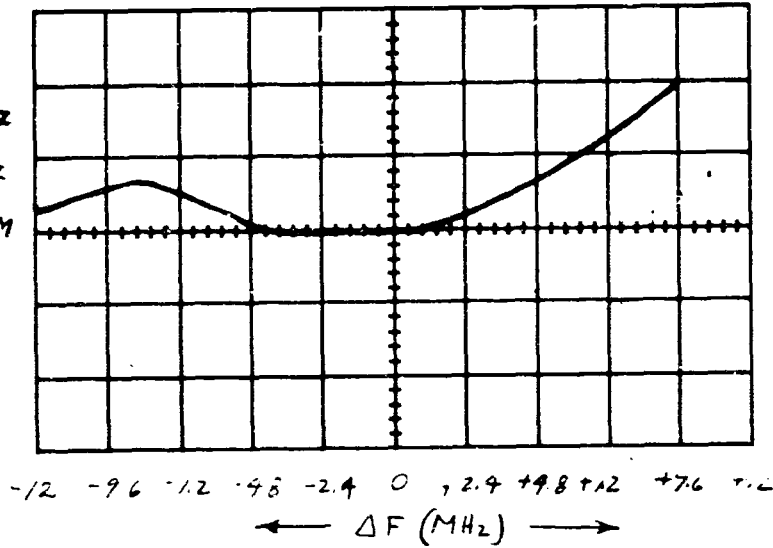
The test data taken with the laboratory system in support of the color link evaluation is presented as Figures 4-22 through 4-25 and Table 4-2. Because color transmission was not required for the CAT Relay Experiment, this data has not been analyzed and refined to any significant extent and should be re-evaluated later if color performance is desired. The data is as follows.

1. Figure 4-22. Receiver threshold characteristic. The weighted noise characteristic was measured with the monochrome noise weighting filter and not the color weighting network<sup>4, 6</sup> as is common practice.



$\Delta\phi$

$FM = 3.58 \text{ MHz}$   
 $BW_{pre} = 30 \text{ MHz}$   
 $BW_{post} = 4 \text{ MHz}$   
 $\Delta\phi = 7.125^\circ/\text{cm}$   
 $\Delta F = \pm 12 \text{ MHz}$

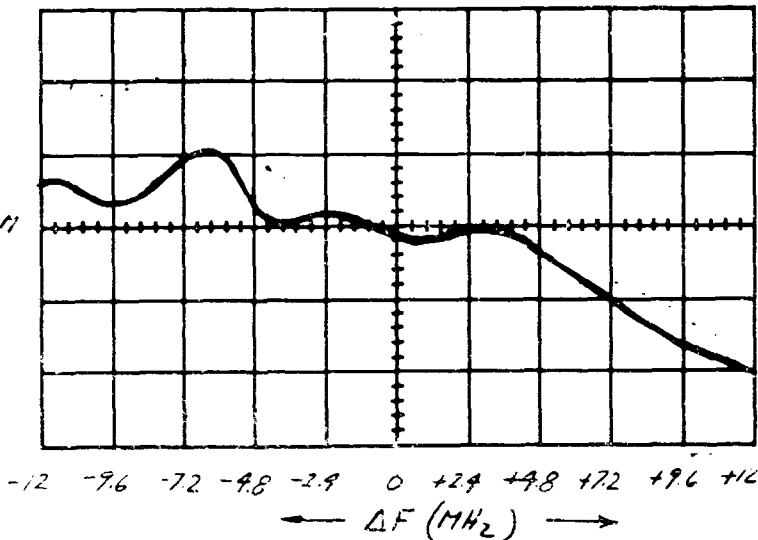


$\Delta\phi$ (DEG.)	$\tau$ (N. Sec)
14.25	11.68
7.125	5.84
0	0
7.125	5.84
14.25	11.68

**FIGURE 4-23**  
 WIDEBAND TRANSMITTER SYSTEM - DIFFERENTIAL  $\phi$  &  $G$

$\Delta G$

$FM = 3.58 \text{ MHz}$   
 $BW_{pre} = 30 \text{ MHz}$   
 $BW_{post} = 4 \text{ MHz}$   
 $\Delta G = 12.5\%/\text{cm}$   
 $\Delta F = \pm 12 \text{ MHz}$

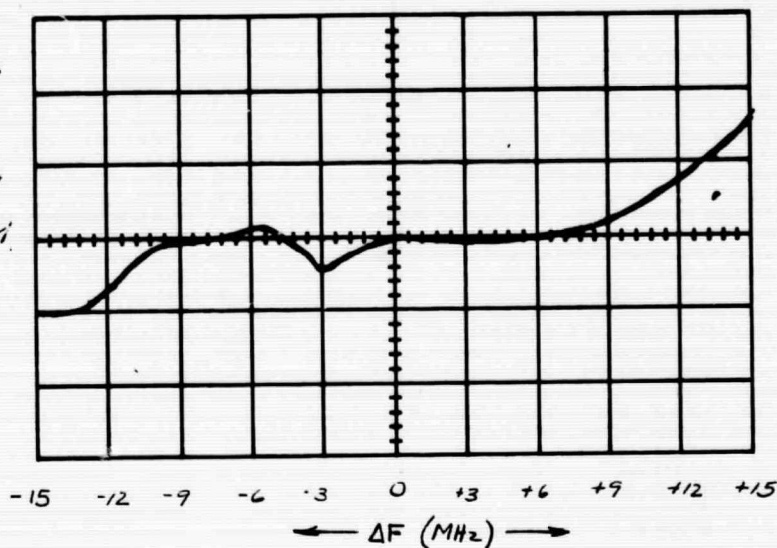


$\Delta G$ (%)	$\Delta G$ (DB)
25	2.5
12.5	1.1
0	0
12.5	1.1
25	2.5

# WIDEBAND TRANSMITTER - DIFFERENTIAL PHASE & GAIN

$\Delta\phi$

$FM = 0.56 \text{ MHz}$   
 $BW_{pre} = 30 \text{ MHz}$   
 $BW_{post} = 2 \text{ MHz}$   
 $\Delta\phi = 2.85^\circ/\text{CM}$   
 $\Delta F = \pm 15 \text{ MHz}$



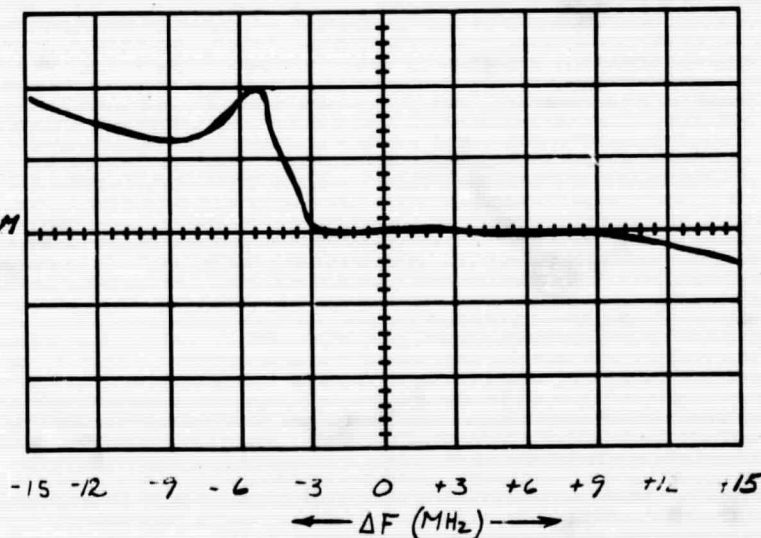
$\Delta\phi$ (DEG)	$\tau$ (N Sec)
5.7	28.4
2.85	14.2
0	0
2.85	14.2
5.7	28.4

FIGURE 4-24

# WIDEBAND TRANSMITTER SYSTEM - DIFFERENTIAL $\phi$ & G

$\Delta G$

$FM = 0.56 \text{ MHz}$   
 $BW_{pre} = 30 \text{ MHz}$   
 $BW_{post} = 2 \text{ MHz}$   
 $\Delta G = 12.5\%/\text{CM}$   
 $\Delta F = \pm 15 \text{ MHz}$



$\Delta G$ (%)	$\Delta G$ (DB)
25	2.5
12.5	1.1
0	0
12.5	1.1
25	2.5

FIGURE 4-25  
WIDE BAND TRANSMITTER UNIT TIME DELAY

VS  
FREQUENCY

(RELATIVE TO DELAY AT 600 KHz)

TIME DELAY - NSEC

+200

+100

0

-100

-200

-300

-400

6 MHz Deviation  
 WITH 15 MHz Error

6 MHz Deviation

6 MHz Deviation

BASE BAND FREQUENCY - MHz

.3

1.0

3.0

10.0

Table 4-2. Wideband Transmitter System Color Characteristics

		Predetection CNR (db) in 20 MHz	
I.	Noise Performance	With Emphasis	Without Emphasis
	Color Noise Just Perceptible	15.0	19.0
	Acceptable Viewing Level	12.5	17.5
	Color Noise Objectionable	6.0	13.0
II.	At 30 db CNR without emphasis		
		Additional System RF Group Delay, Distortion (Composite of linear, parabolic and ripple)	
	Color Shift Just Perceptible		10 nsec p-p
	Color Shift Allows Acceptable Viewing		20 nsec p-p
	Color Shift Objectionable		50 nsec p-p
III.	Test Evaluation Conditions		
	$\Delta f = \pm 9$ MHz		
	Voice Subcarrier Off		
	Predetection $BW_3 = 20$ MHz		
	Postdetection BW = 4 MHz		
	Receiver Threshold = 9 db		

2. Figures 4-23, 4-24. The differential phase and gain characteristics of the Wideband Transmitter system are recorded with 3.58 MHz and 0.56 MHz tones.
3. Figure 4-25. The baseband group delay characteristic is shown for the Wideband Transmitter alone. A completely different measurement technique was used and no attempt was made to correlate with Figures 4-23, 4-24.

In summary, Table 4-2 lists the C/N and group delay distortion color transmission requirements for the Wideband Transmitter system.

#### 4.5 PM UPLINK TESTS

A simulation of the Experiment uplink ranging or subcarrier formats was not possible because proper test equipment is not available, however, substitution of a monochrome video signal was used to provide a demonstration of the SGLS Receiver. The simulated link block diagram is shown in Figure 4-26. For the purposes of this simulation only, the SGLS Receiver has been modified for a  $2\beta_{LO}$  bandwidth of 20 Hz in order to increase the low frequency response. The normal SGLS  $2\beta_{LO}$  bandwidth of 1000 Hz yields a strong signal 3 db cutoff of about 700 Hz which is intolerable for television video demodulation. The baseband to baseband frequency response of the simulated link is shown in Figure 4-27. Group delay nonlinearity over the 3 db bandwidth is negligible. Also shown in Figure 4-27 is the frequency response of the SGLS Receiver as it will be used in the recommended CAT Relay System.

The PM deviation was set at 1.16 radians (equipment maximum) and the picture quality versus SNR evaluated. It was evident that an excellent quality picture is not possible with this equipment combination. A 25.7 db pre-detection SNR is the maximum obtainable with the SGLS Receiver as is shown in Figure 4-28, resulting in a (S+N) p-p/Nrms ratio of 34.7 db (unweighted). This is about 9 db less than the 43.5 db SNR goal set for the Experiment FM downlink. Examination of Figure 4-28 and the SGLS Receiver design show that this result is to be expected since the receiver is optimized for sensitivity (-126 dbm threshold) and therefore runs out of dynamic range at relatively strong signal input level (-65 dbm).

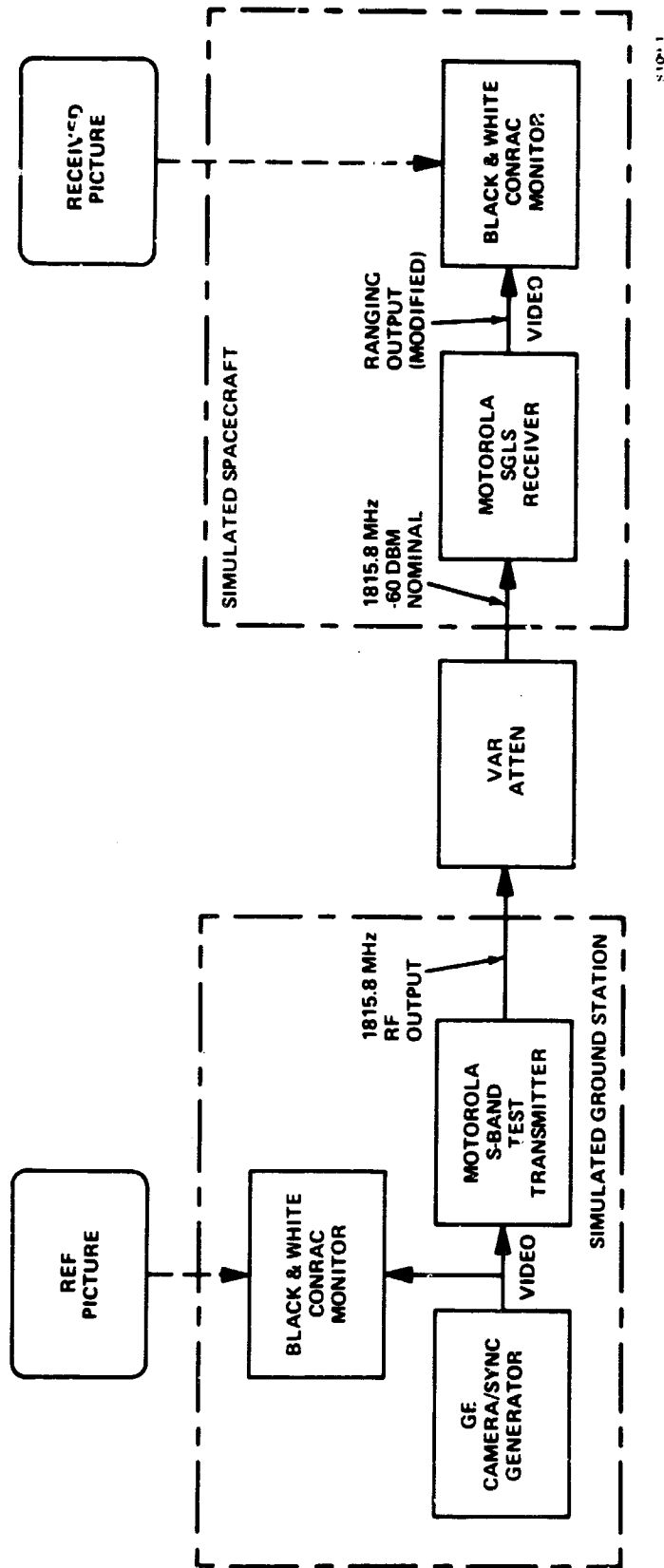
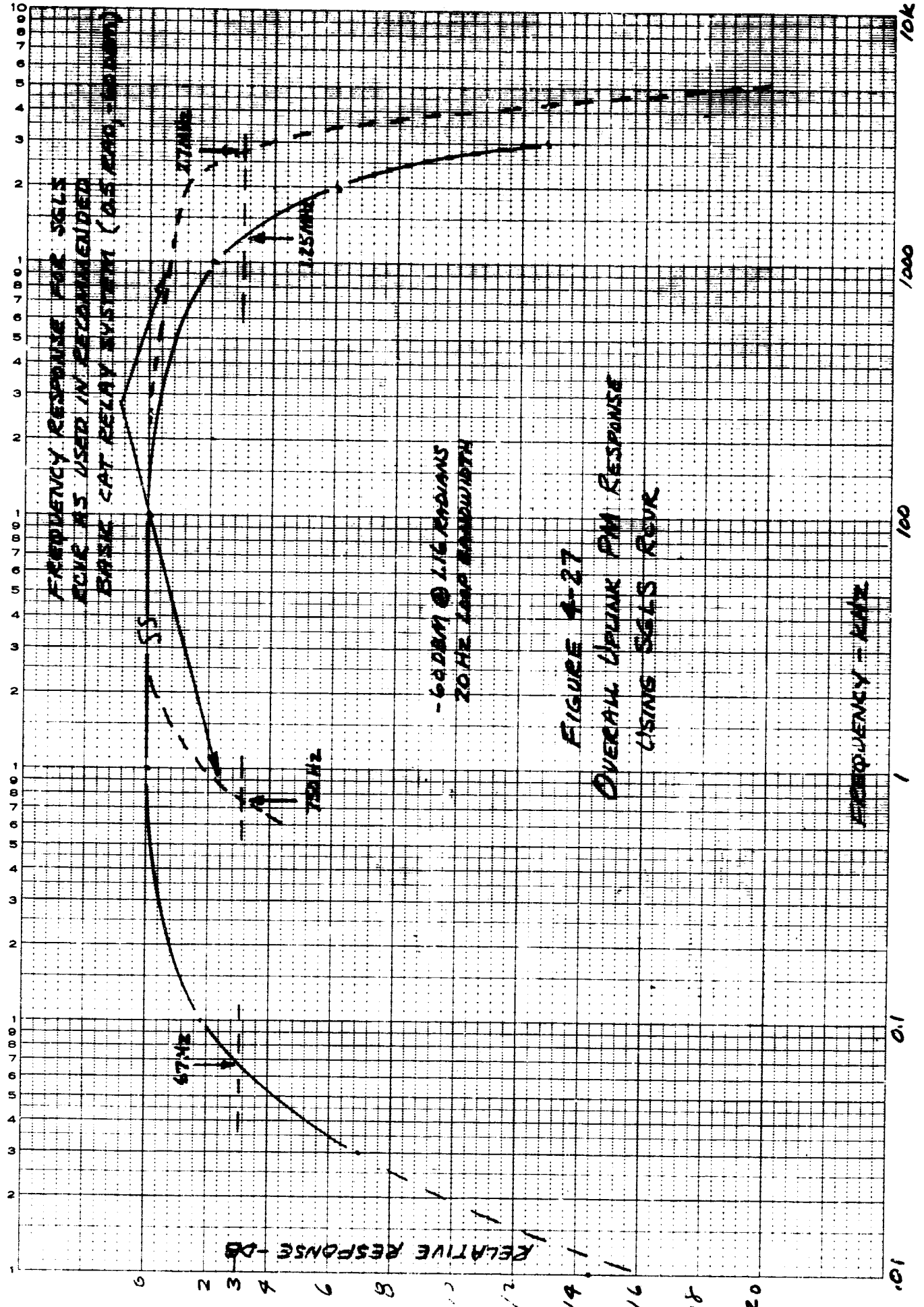


Figure 4-26. Simulated PM Uplink System



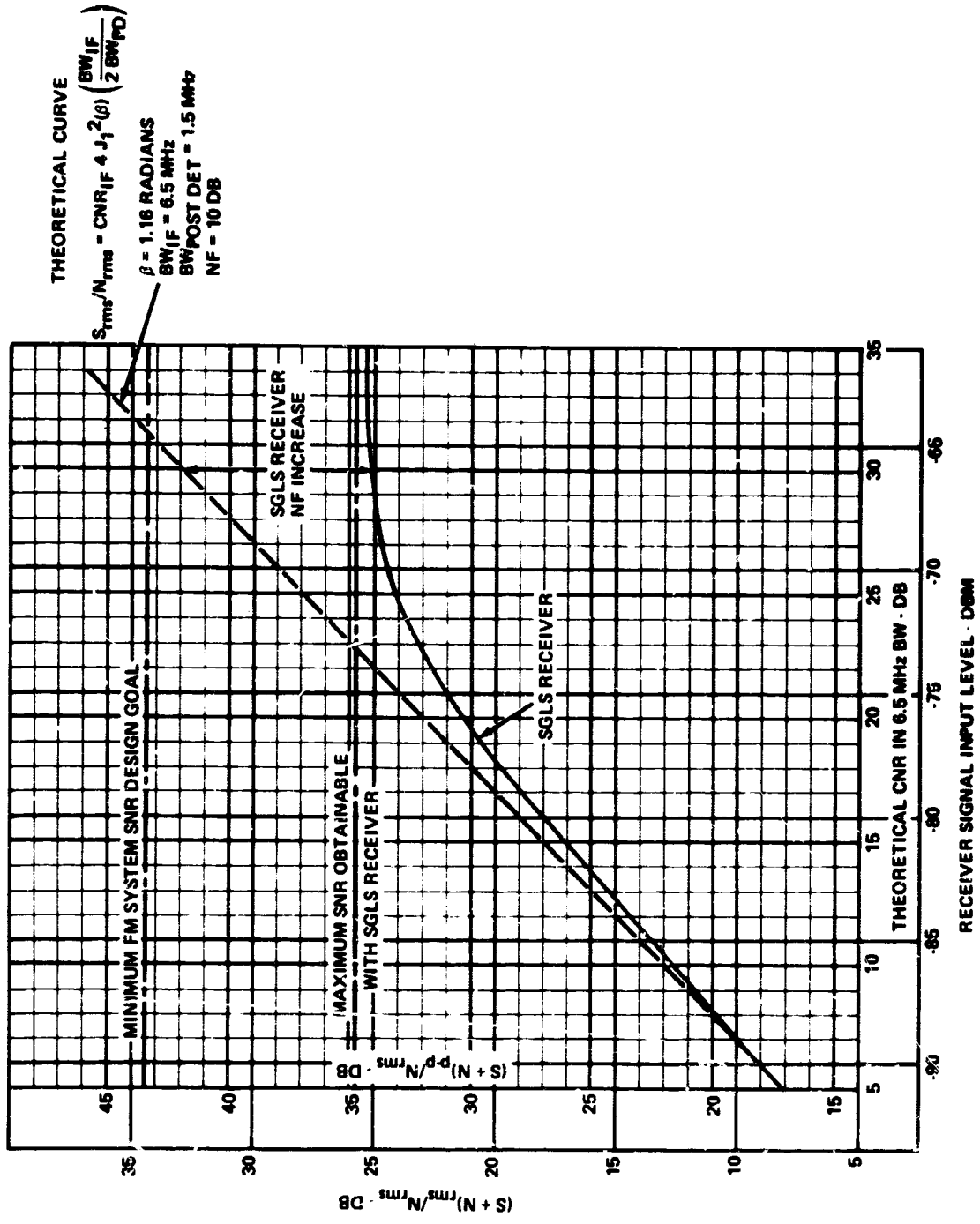


Figure 4-28. SNR at Baseband - PM Link

Increasing the uplink deviation to 1.8 radians will increase the SNR by 1.6 db, but increasing beyond that decreases the SNR ( $J_1(X)$  decreases). Assuming these uplink operating conditions and 2 MHz post detection bandwidth, an estimated 35 db SNR (weighted  $(S+N)_{p-p}/N_{rms}$ ) picture could be obtained on the AAC spacecraft with the recommended CAT Relay System (with preamplifier) by adding a narrowband loop mode of operation. Extrapolation of the results of the quality survey (Table 10-1) indicate that about 60% of the viewers would consider this to be a fine or passable picture. Observation of the 34.7 db unweighted SNR picture mentioned above shows the displayed noise is not quite as objectionable as the quality survey picture because of the absence of FM click noise.

Obviously, strengthening the uplink by increasing the ATS-F transmitter power of AAC antenna gain would enhance the received picture quality. Uplink TV might possibly be considered for the Experiment and subsequent operational evaluation if an analysis were initiated which could successfully determine the feasibility of a modified system with respect to narrowband tracking capability, ATS-F operation in an unlocked uplink mode or narrower bandwidth and availability of TV monitors aboard the AAC.

## REFERENCES

- 4.1 Carlowe, J., CAT Relay Laboratory Test Program Report, Motorola Report 3503-10/TM CWT-175, December 1968.
- 4.2 Television/Audio Link Demonstration, NASA Communications and Tracking Relay Experiment, Motorola Report 3503-4, October 1968.
- 4.3 CCIR Recommendation 451, p. 102.
- 4.4 EIA Standard RS 250A, p. 19.
- 4.5 Transmission Systems for Communications, Bell Telephone Laboratories, 1964, p. 495.
- 4.6 EIA Standard RS 250-A.

## SECTION V

### 5. CLUSTER EQUIPMENT TRADEOFF STUDIES

Upon completing the system design analysis and the laboratory and demonstration program, several trade-offs should be considered and resolved prior to recommending the CAT Relay Experiment equipment. These all involve the AAC equipment and include the selection of a Steerable Antenna Subsystem, the antenna size-transmitter power tradeoff, and the equipment location aboard the cluster.

#### 5.1 STEERABLE ANTENNA SUBSYSTEM

Five steerable antenna subsystems are candidates for consideration on the AAC. Preliminary information only is available on these subsystems since a comprehensive subsystem specification has not been generated on this program. In retrospect, Table 5-1 summarizes the general requirements for the antenna subsystem as concluded from the foregoing sections. To satisfy the Experiment goal of using existing qualified equipment wherever possible, only one antenna appears to be applicable, the Dalmo-Victor High Gain Antenna used on the Apollo CSM. This antenna, however, only has about 27 db of gain and is quite expensive, having been designed for man-rated highly-reliable use. This antenna has, temporarily at least, been discarded in favor of reviewing some newer antenna designs which appear to be more applicable to the experimental nature of the CAT Relay System and have more gain potential. The steerable antenna subsystems under consideration are

1. General Dynamics expandable truss antenna with lightweight gimbal.
2. General Dynamics expandable truss antenna with Dalmo-Victor gimbal
3. Motorola phased array goniometer antenna system
4. TRW thin film deployable antenna.

Table 5-2 is a preliminary summary of the major characteristics of these antennas taken from vendor publications 5.1, 5.2 which were based upon an early program opinion that a 10 foot, deployable antenna would be required. The subsequent sections provide a short description of each antenna. The General Dynamics antenna has been chosen as the conceptual antenna design for the purposes of this report. Final selection of an antenna subsystem will occur after competitive proposals are solicited from a procurement specification during the next program phase.

Table 5-1. Steerable Antenna Subsystem Requirements Summary

Azimuth Scan Capability	360°
Possible Reduced Requirement	90° to 270°
Elevation Scan Capability	±5.2°
Azimuth/Elevation Slew Rate	.006°/sec max.
Steering	Open loop from ground commands
Pointing Accuracy (Excluding S/C)	0.1 beamwidth
Minimum Gain (At rotary joint)	31.9 db @ 2250 MHz
Polarization	RCP
Deployment Required	Reflector, boom position
Weight	Unspecified
Power	Unspecified

The General Dynamics antenna subsystem consists of an expandable-truss hexagonal-reflector (10 foot diameter aperture) with an adjustable reflective mesh (see Figure 5-1) a center-supported feed-mast, two-degree-of-freedom gimbal (lightweight ±20° on each axis or Dalmo-Victor servo controlled), triangular aluminum truss (10-foot-rigid) boom with deployment actuator and electronic equipment for deployment and open-loop steering. The antenna assembly can also be supplied on a deployable triangular boom. Details of the proposed design are given in reference 10.1 and Figure 6-7 is a conceptual picture of the antenna system structure and mounting.

The Motorola antenna subsystem is a fixed position, circular phased array. The goniometer required is a beam forming and scanning matrix for the array consisting of a lens to accurately phase the array element signals, a diode switch matrix for proper antenna element and transmitter connections to the lens terminals and control logic and drivers for the switch matrix. A conceptual installation is shown in Figure 5-2 and additional subsystem details are given in Appendix A.

The TRW antenna subsystem consists of an expandable 10-foot diameter parabolic reflector utilizing an aluminized mylar skin supported by collapsi-

Table 5-2. Comparison of Antenna Subsystems

Parameter	General Dynamics Expandable Truss - Light Weight Gimbal	General Dynamics Expandable Truss - Dalmo-Victor Gimbal	TRW Thin Film, Pole Boom	Motorola Phased Array Goniometer
AAC Location	Aft Interstage Area	Aft Interstage Area	Aft Interstage Area	Periphery of Fwd Skirt
Deployment	Expand Antenna, Rotate Boom	Expand Antenna, Rotate Boom	Untie Antenna, Rotate Boom	None
Scan Pattern	+10° AZ, ±10° EL	270° AZ, +90° EL	270° AZ, ±90° EL	360° AZ, 10° EL
Scan Increments	Continuous	Continuous	.03° AZ, .03° EL	1.2° AZ, 6.5° EL
Aperature Gain	34.0 db	34.0 db	33.0 db	37.0 db
Feed, Joint, Polarizer Loss	1.0 db	1.0 db	0.7 db	3.1 db
Cable Loss	1.5 db	1.5 db	1.5 db	3.9 db
Connector Loss	0.5 db	0.5 db	0.5 db	0.2 db
Pointing Loss	0.5 db	0.5 db	0.5 db	1.5 db
Net Antenna Subsystem Gain	30.5 db	30.5 db	29.8 db	28.3 db

Table 5-2. Comparison of Antenna Subsystems (cont)

Parameter	General Dynamics Expandable Truss - Light Weight Gimbal	General Dynamics Expandable Truss - Dalmo-Victor Gimbal	TRW Thin Film, Pole Boom	Motorola Phased Goniometer Array
Reflector	30 lbs	30 lbs	7 lbs	(310 element groups) 67 lbs
Gimbal	5 lbs	20 lbs	10 lbs	(Lens) 8 lbs
Boom (10 ft)	9 lbs *	9 lbs *	10 lbs*	(Cable) 113 lbs
Steering Control	5 lbs	5 lbs	5 lbs	50 lbs
Deployment	10 lbs	10 lbs	10 lbs	0
Total Antenna Weight	59 lbs	74 lbs	42 lbs	238 lbs
DC Power (Servo)	30 Watts Ave	40-60 Watts	5 Watts Ave	5 Watts

All Parameters Estimated

\* For 25 foot boom (360° AZ, +90° - 180° EL scan pattern) add 16 lbs.

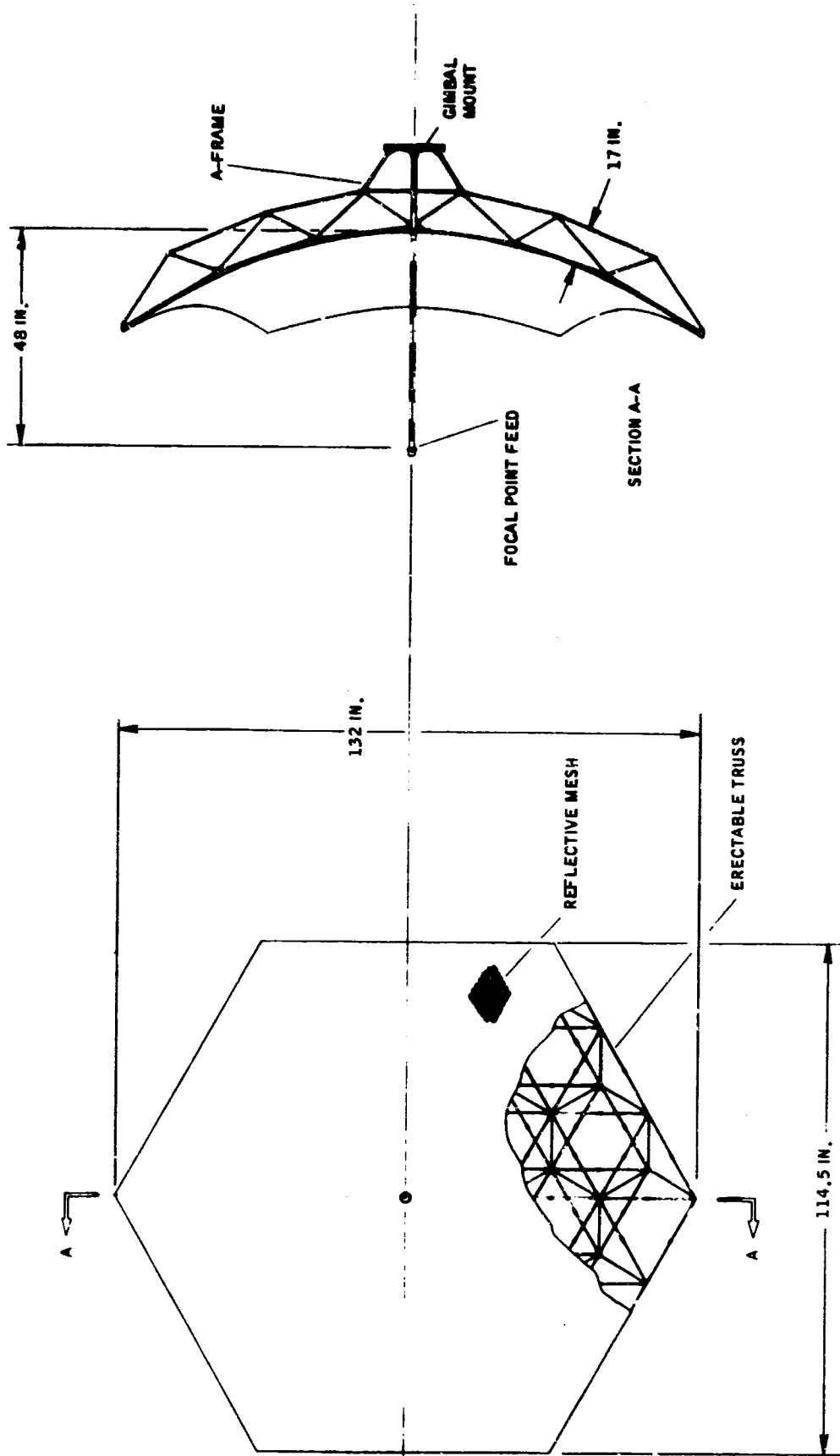
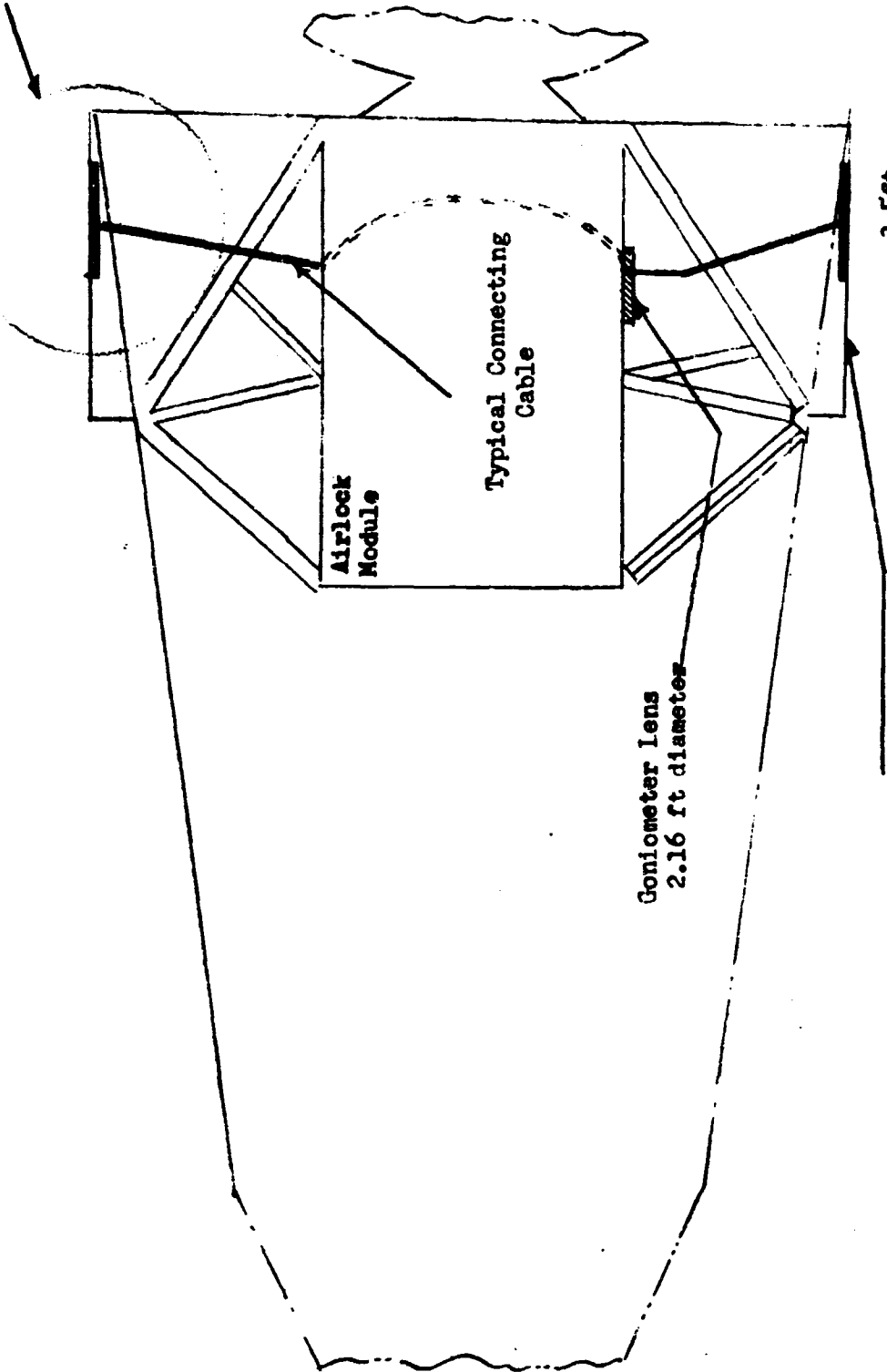


Figure 5-1. "General Dynamics Reflector Design"

Array Elements



3-584

Goniometer Lens  
2.16 ft diameter

Antenna Mounting Surface  
Cluster SLA of Workshop  
Forward Skirt

FIGURE 5-2 MOTOROLA GONIOMETER INSTALLATION CONCEPT

ble radial ribs, a center-supported feed-mast, two-degree-of-freedom gimbal, tubular boom with deployment actuator, and electronic equipment for deployment and open-loop steering. Figure 5-3 depicts the reflector detail and Figure 5-4 the SIVB mounting concept. The TRW antenna can also be supplied on the end of a deployable 3-D nesting pantograph boom.

A potential requirement for any mechanically steered antenna subsystem would be  $360^{\circ}$  azimuth control for contact with the ATS-F during any orbital pass. Assuming the antenna is on a ten foot mast as pictured in this report or on a perpendicular boom in the Airlock area will only permit approximately  $270^{\circ}$  of steering before being blinded by the vehicle proper or the aft engine. This requirement can be eliminated by specifying an aft boom length in the order of 25 to 30 feet or by restricting the potential r-f contacts to the ATS-F with a  $90$  to  $270^{\circ}$  azimuth control specification. For the latter case, installation in the Airlock or Aft Engine areas would be feasible.

Either parabolic reflector has the capability of larger aperture size if required. The phased array goniometer is not practically capable of higher gain than that defined (about 28 db).

## 5.2 ANTENNA SIZE-TRANSMITTER POWER TRADEOFF

The required AAC effective radiated power at 2250 MHz has been determined as 69.8 dbm minimum (from Figure 3-6) for the minimum link quality specified in Table 3-1. This level can be obtained by various combinations of transmitters and antenna apertures. Also to be considered is the economical obtainment of some additional link margin to guard against unforeseen losses. Starting with an 11 watt transmitter (Motorola Wideband Transmitter) and a ten foot diameter reflector, a comparison of some representative combinations are tabulated in detail in Table 5-3 and the more promising entries summarized in Table 5-4. The potential link improvement of any other attractive antenna or transmitter can easily be determined using Figure 3-6.

The No. 1 transmitter-antenna system in Table 5-3 is a duplication of the all-worst-case link parameters listed in Table 3-2. Conversely, No. 2 is the all-best-case link parameters. It is expected that such a system, if the link parameter bounds are correct, would end up somewhere between these two limits, perhaps with 4 db margin over the minimum requirement. Subsequent entries in Table 5-3 repeat the link for the Collins CSM TWA (14.8 watts), the Watkins Johnson WJ 448 (35 watts) and WJ 395 (100 watts) TWA's, 10 and 14.1 foot parabolic antennas, and the Motorola goniometer. As a preliminary tradeoff to narrow down the potential systems, the CSM TWTA has been eliminated since a 14.8 watt TWT transmitter offers little advantage over the 11 watt solid state transmitter (1 db), the Watkins Johnson WJ 395 eliminated because the unit is not space qualified and the Motorola

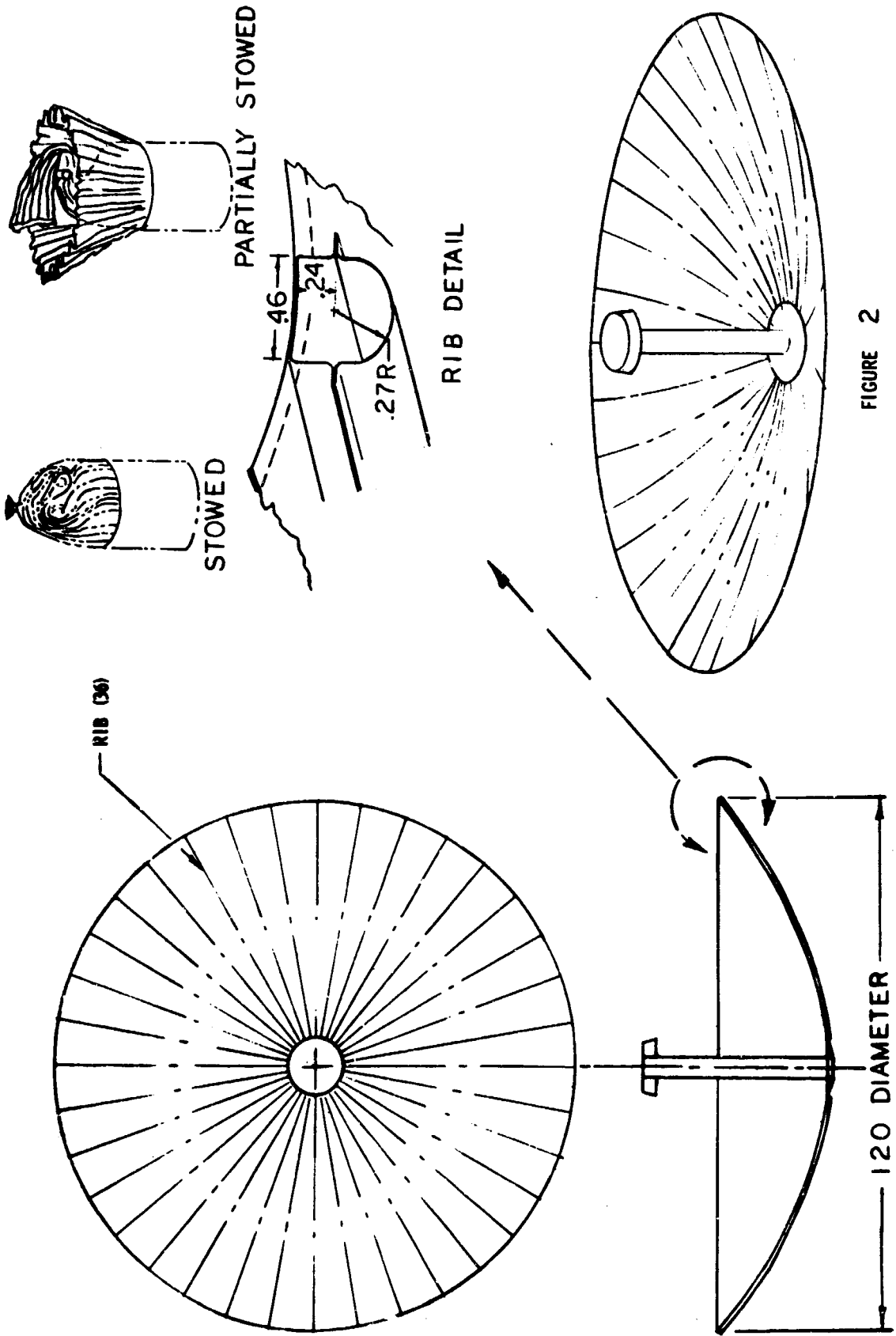


FIGURE 2

Figure 5-3. TRW Antenna Detail

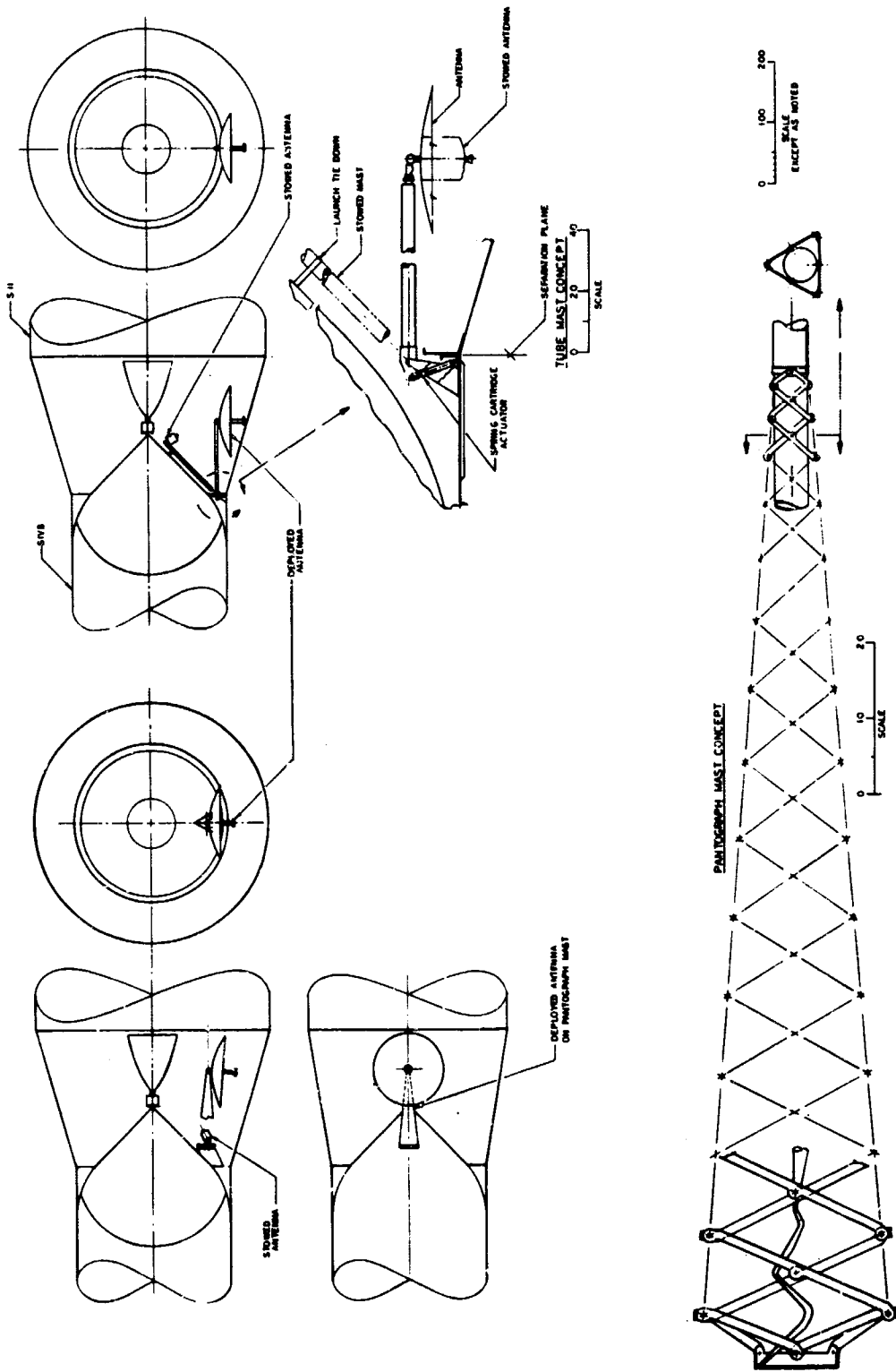
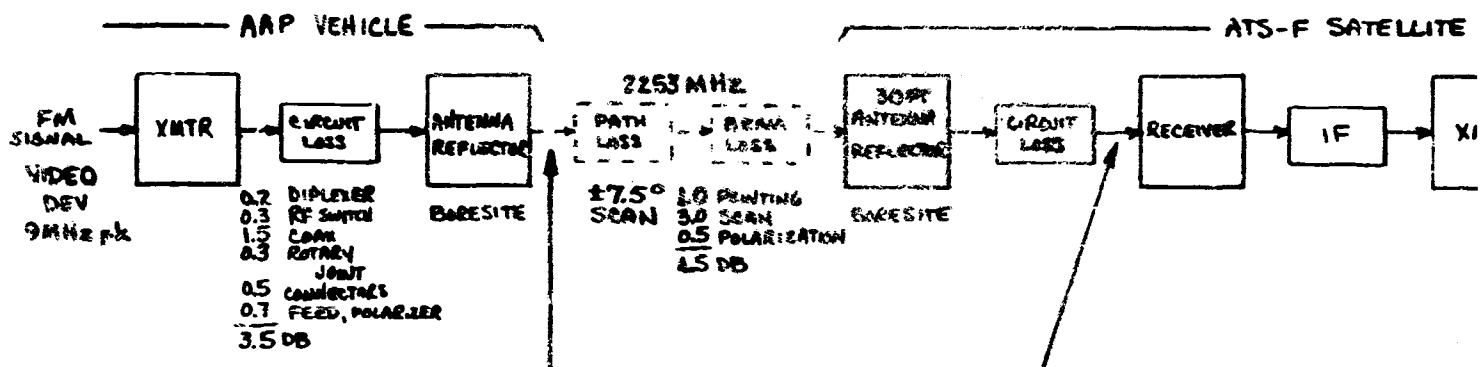


Figure 5-4. Antenna Installation Concept

Table 5-4. Transmitter - Antenna Size Tradeoff Summary

Table 5-3 Number	System Description	Rec'd IF CNR DB	Margin Above 7 DB	Post. Det. SNRW	Relative Improve- ment DB	Approximate Program Cost Increase	Advantages
1	Basic System Described in Figure 6-1	7.9	0.9	48	0	Reference	Most Economical for Capability Provided
3	Basic System with 14.1 Foot Antenna	10.3	3.3	51	3	5% (TRW Antenna) 11% (GD Antenna)	Economical Since Antenna Must be Designed
5	Basic System with WJ 448 TWTA added	11.9	4.9	53	5	11%	See Paragraph 7.1

TABLE 5-3. LINK COMPARISON C



No.	DESCRIPTION	RF P <sub>0</sub>		CKT LOSS DB	ANTENNA		ERP DBM	MAXIMUM LOSS		ANTENNA GAIN-DB	CKT LOSS DB	MIN SIG LEVEL DBM	RECEIVER		IF	
		W	DBM		SIZE FT	GAIN DB		PATH-DB	BEAM-DB				NF DB	C/N DEN DB-Hz	BWN MHz	CNR DB
1	SPEC'D ATS-F WIDEBAND XMITR 10FT AAP ANT	11	40.4	3.5	10	34	70.9	191.7	4.5	41	3	-87.3	5	81.7	40	5
2	TOTALLY OPTIMISTIC NO.1	12	40.8	2.8	10	34.5	72.5	191.7	2.0	43	2	-86.2	4	89.8	40	13.8
3	NO.1 WITH 14.1FT ANT	9	39.5	3.5	14.1	37	73.9	191.7	4.5	41	3	-84.3	5	84.7	40	8.7
4	NO.1 WITH CSM TWT	14.8	41.7	3.5	10	34	72.2	191.7	4.5	41	3	-86.0	5	83.0	40	7.0
5	NO.1 WITH WJ 448 TWT	35	45.4	3.1 <sup>①</sup>	10	34	76.3	191.7	4.5	41	3	-81.9	5	87.1	40	11.1
6	NO.4 WITH 14.1FT ANT	14.8	41.7	3.5	14.1	37	75.2	191.7	4.5	41	3	-83.0	5	86.0	40	10.0
7	NO.5 WITH 14.1FT ANT	35	45.4	3.1 <sup>①</sup>	14.1	37	79.3	191.7	4.5	41	3	-78.9	5	90.1	40	14.1
8	NO.1 WITH WJ 395 TWT	100	50	3.5 <sup>②</sup>	10	34	80.5	191.7	4.5	41	3	-77.7	5	91.3	40	15.3
9	NO.8 WITH 14.1FT ANT	100	50	3.5 <sup>③</sup>	14.1	37	83.5	191.7	4.5	41	3	-74.7	5	94.3	40	18.3
10	SPEC'D ATS-F, WIDEBAND XMITR, GONNOMETER	11	40.4	0.7 <sup>④</sup>	-	30	69.7	191.7	5.5 <sup>④</sup>	41	3	-89.5	5	79.5	40	3.5
11	NO.10 WITH WJ 448 TWT	35	45.4	0.7 <sup>⑤</sup>	-	30	74.7	191.7	5.5 <sup>④</sup>	41	3	-84.5	5	84.5	40	8.5
12	NO.10 WITH WJ 395 TWT	100	50	1.1 <sup>⑤</sup>	-	30	68.9	191.7	5.5 <sup>④</sup>	41	3	-80.3	5	88.7	40	15.7

① ATS-F POSITION AT 148° W.

⑤ DIPLEXER-0.2DB, RF SWITCH

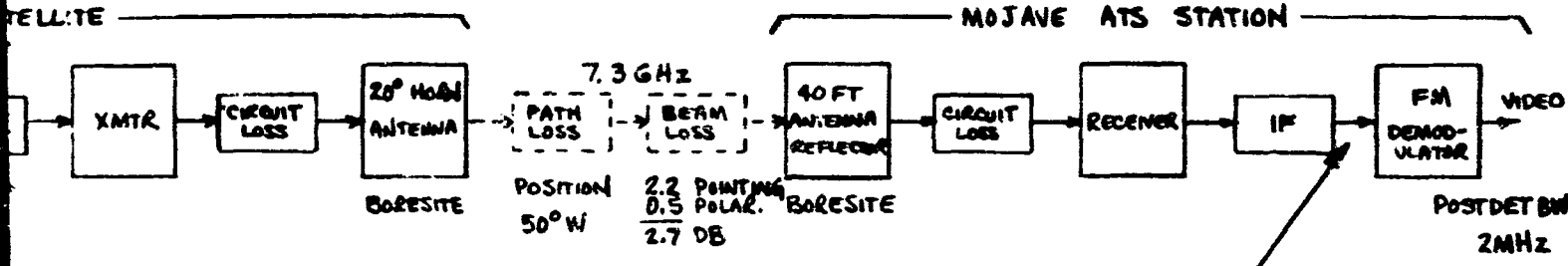
② (S+N)<sub>p-p</sub>/N<sub>rms</sub> WEIGHTED FROM FIGURES 3-4 AND 3-5.

⑥ POINTING-2.0DB, SCAN-3.0

③ DELETION OF SERIES RF SWITCH SAVES 0.4 DB.

④ ASSUMES 0.4 DB INCREASE IN LOSSES TO HANDLE 100W POWER.

# COMPARISON OF TRANSMITTER-ANTENNA SYSTEMS



F	RF P <sub>0</sub>		CKT LOSS DB	ANT GAIN DB	ERP DBM	MAX LOSS		ANT GAIN DB	CKT LOSS DB	RCNR		TOTAL DMLK CNR-D DB-HZ	IF BW MHZ	REC'D CNR			DEMOD			N O.	
	CNR DB	W				DBM	PATH DB			BEAM DB	N TEMP °K			ATS LK CH-D BT-HZ	IF DB	REC'D DB	MARG DB	TYPE	THRESH DB		POSTD. THRESH DB(D)
	5	24	43.8	2	18	59.8	202.4	2.7	56	0.1	100	89.3	81.0	20.5	7.9	7.0	+0.9	TED STD	6 9	48 47	1
	13.8	25	44	1	18	61	201.7	1.5	57	0.1	90	94.3	88.5	20	15.5	7.0	+8.5	TED STD	6 9	56.5 56.5	2
	8.7	24	43.8	2	18	59.8	202.4	2.7	56	0.1	100	89.3	83.4	20.5	10.3	7.0	+3.3	TED STD	6 9	51 51	3
	7.0	24										89.3	82.1	20.5	9.0	7.0	+2.0	TED STD	6 9	50 49	4
	11.1	24										89.3	85.0	20.5	11.9	7.0	+4.9	TED STD	6 9	53 53	5
	10.0	24										89.3	84.3	20.5	11.2	7.0	+4.2	TED STD	6 9	52 52	6
	14.1	24										89.3	86.7	20.5	13.6	7.0	+6.6	TED STD	6 9	54.7 54.7	7
	15.3	24										89.3	87.2	20.5	14.1	7.0	+7.1	TED STD	6 9	55.3 55.3	8
	18.3	24										89.3	88.1	20.5	15.0	7.0	+8.0	TED STD	6 9	56.7 56.2	9
	3.5	24										89.3	79.1	20.5	6.0	7.0	-1.0	TED STD	6 9	43.3 40.8	10
	8.5	24										89.3	83.2	20.5	10.1	7.0	+3.1	TED STD	6 9	50.5 50.5	11
	15.7	24	43.8	2	18	59.8	202.4	2.7	56	0.1	100	89.3	86.0	20.5	12.9	7.0	+5.9	TED STD	6 9	54 54	12

SAME

RF SWITCH - 0.3 DB, COAX - 0.1 DB, CONNECTORS - 0.1 DB; TOTAL = 0.7 DB.

CAN - 3.0 DB, POLARIZATION - 0.5 DB; TOTAL = 3.5 DB

12-28-68

goniometer eliminated because of the complexity and weight penalty and limited elevation scan capability.

The remaining three transmitter-antenna systems are summarized in Table 5-4. No. 1 is selected as the recommended CAT Relay system because it is the most economical while exceeding the basic requirement. No. 3 and 5 are then recommended as "expansion bargains" if program funding is available. Both No. 3 (antenna increased to 14.1 foot diameter) and No. 5 (addition of WJ 448, 35W TWT) are add-ons to the basic system (No. 1) and the units are discussed in more detail in Section 7.

### 5.3 AAC EQUIPMENT LOCATION

There are a minimum of three major Cluster areas to be considered for installation of the majority of the CAT Relay equipment. These are (1) the Airlock Module exterior to the crew tunnel, (2) the Forward SIVB (workshop) Skirt area and (3) the Aft SIVB Skirt area. The Instrumentation Unit was not considered, however, if it is a potential site, the comments on the Forward Skirt location would apply. The Relay Experiment controls for crew operation are expected to be located in the experiment area of the crew quarters no matter where the other equipment is located.

There are several important factors which must be considered in choosing from the three postulated equipment locations or any additional potential locations. They are:

1. Proximity of the transmitter to the antenna.
2. Antenna storage and deployment requirements.
3. Environmental conditions.
4. Avoidance of man-rated compartments (except controls).
5. Modifications required to existing vehicle equipment and installation costs.

Table 5-5 provides a tabulated comparison of these three location areas.

Based on the potential selection of one of the steerable reflector antenna systems, the Aft Skirt area has been selected as the installation area of the antenna boom and major r-f units in order to eliminate the need for a deployable boom. The less cable loss sensitive components would then be located in the Forward Skirt area. This is a preliminary selection without consultation aid from the integration subcontractor (not assigned) and subject to

Table 5-5. Comparison of Potential AAC Equipment Location Sites

Potential Location	Antenna/Transmitter Proximity	Antenna Storage and Deployment	Environmental Conditions		Required Modifications	Comments
			Vibration	Thermal		
Airlock Module	<p>1. For Conservative Installation: Longer Antenna Boom Required, XMTR Not Locatable At Boom Base - Higher R-F Loss. Goniometer Is Exception.</p> <p>2. However, Transmitter Might Be Located At End Of Large Deployable Boom.</p>	<p>1. Deployable Boom Required For Dishes.</p> <p>2. Panels Required For Goniometer</p>	<p>Lower Vibration Than Aft Skirt</p>	<p>Active Control System - 30° to 100°F Nominal</p>	<p>1. New Equip. Boxes For Electronics</p> <p>2. Mounting For Deploy. Boom Base</p> <p>3. Access Through Environmental Curtain</p>	<p>1. Vehicle Prevents 360° Dish Rotation.</p> <p>2. Potential ATM Interference.</p> <p>3. Closer Workshop To Solar Panels</p> <p>SECOND CHOICE</p>
Workshop Forward Skirt	Same As Above	No Outside Access Available For Deployable Dishes	Equipment Panels Vibration Isolated	Cold Rails Available	Access To Exterior	<p>1. Best Location For Goniometer</p> <p>2. Closest To Workshop Solar Panels</p> <p>3. Available Panels For Unit Mounting</p>

Table 5-5. Comparison of Potential AAC Equipment Location Sites (Cont.)

Potential Location	Antenna/Transmitter Proximity	Antenna Storage and Deployment	Environmental Conditions		Required Modifications	Comments
			Vibration	Thermal		
Workshop AFT Skirt	<p>1. Transmitter At Base Of Antenna Boom</p> <p>2. Transmitter Might Be Located In Rigid Triangular Boom (General Dynamics)</p>	<p>1. No Room For Goniometer Lens Mounting</p> <p>2. No Problem For Dish On Boom</p>	<p>1. Expect Maximum Vehicle Vibration</p> <p>2. Equipment Panels Vibration Isolated</p>	<p>No Thermal Control Available Except Warm Air At Pre-Launch</p>	<p>1. Two Equip. Panels Must Be Vacated</p> <p>2. Boom Tether, Lift Off Restraint</p> <p>3. Access Through Thermal Curtain</p>	<p>Potential For 360° Dish Rotation With Long Boom</p> <p>FIRST CHOICE</p>

change. This location will be used to explain the potential equipment location concepts in Section 6.

#### REFERENCES

- 5.1 Ten-Foot Diameter Expandable-Truss Antenna for Apollo Applications Spacecraft, Proposal, Report No. GDC PIN68-844, Convair Division of General Dynamics, 15 October 1968.
- 5.2 TRW Thin Film Deployable Antenna, SIVB Workshop Application, TRW Systems Group, 12 December 1968.

## SECTION VI

### 6. BASIC CLUSTER CAT RELAY EQUIPMENT

This section defines and details the Motorola recommended basic CAT Relay System to be installed in the cluster and which will perform the program objectives. This system is capable of expansion and modification to provide additional operating margin and capability as discussed in Section 7.

#### 6.1 RECOMMENDED BASIC SYSTEM

The recommended system is the culmination of the analysis and laboratory test detailed in the preceding sections and is diagrammed in Figure 6-1. The generic background of each of the recommended system units is given in Table 6-1 along with the Motorola Report 3503-4 reference location for additional descriptive material. The Motorola Wideband Transmitter and SGLS Receiver are shown in Figures 6-2 and 6-3. These units are space-qualified, high reliability solid state designs. The Steerable Antenna Subsystem for flight equipment use will be selected from among the subsystems discussed in paragraph 5.1. The remainder of the equipment is presently off-the-shelf with slight modifications with the exception of the Baseband Processor unit and the Control/Monitor Panel. Both of these units contain a high percentage of space qualified circuit designs which will be repackaged in a single compact unit. Table 6-2 is a preliminary weight and power summary for the equipment to be added to the AAC.

#### 6.2 EQUIPMENT DESCRIPTION

As indicated in Table 6-1, the majority of the units are described in more detail in Motorola Report 3503-4 Appendices. The transponder section (Receiver, Baseband Processor, Phase Modulator, and Transmitter) preliminary specification and description of the Baseband Processor, Control/Monitor Panel and Omni-Antenna are included in this section.

The transponder is capable of coherently receiving and transmitting signals between the AAC and the ATS-F, which are phase modulated with the link services defined in Table 2-4. The baseband and transmitter unit will also be capable of frequency modulation of a non-coherent carrier with the monochromatic commercial quality television and crew voice signals originating from the AAC. The performance listed in Tables 6-3 and 6-4 will be obtained with the Motorola manufactured transponder units.

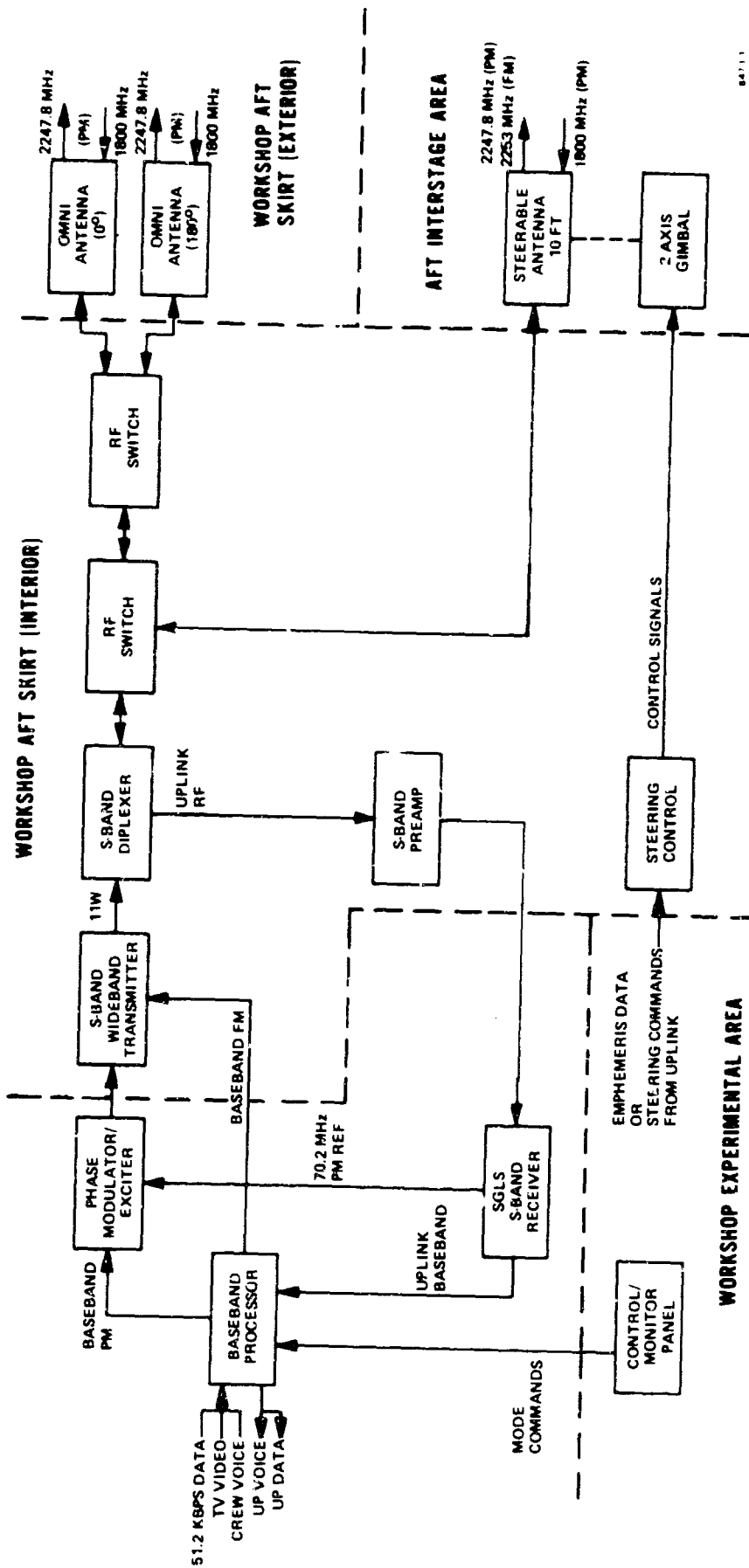


Figure 6-1. Recommended Basic CAT Relay Cluster Equipment

Table 6-1. CAT Relay Basic Equipment History

No.	Unit	Qualification	Modifications Required	Motorola Report Description Location
1.	Control and Monitor Panel	Will use LM/CSM components	New design	None
2.	Baseband Processor	SCO's, filters and amplifiers from AF Qualified SGLS, MOL. Disc from CSM PMP.	Assemble in new housing	Obsolete
3.	SGLS Receiver	AF qualification on SGLS	Delete FSK command module, ranging output filter.	Appendix B-1
4.	Wideband Transmitter	Space qualified	Add PM input and switch.	Appendix B-2
5.	RF Latching Switch	Rugged construction for satellite applications.	Possibly replace with diode or ferrite switch.	Appendix B-8
6.	S-Band Dream. fier	Aircraft qualified, rugged construction	Add isolator	Appendix B-6
7.	Phase Modulator/Exciter	Constructed with same techniques as Motorola SGLS equipment.	Package modules designed on NAS9-7483	Obsolete
8.	S-Band Diplexer	AF qualification on SGLS	None	Appendix B-7

Table 6-1. CAT Relay Basic Equipment History (cont)

No.	Unit	Qualification	Modifications Required	Motorola Report 3503-4 Description Location
9.	Omni -Antenna	Deployable waste designed for Army field use	Change r-f input to waveguide	None
10.	Steerable Antenna Subsystem	Similar General Dynamics antenna designs studied and designed under current or recent NASA contracts*	Increase size of reflector, design steering control.	None

\*See reference 5.1, Section 2 for more details.



4.5 x 8 x 12  
432 cu. in.  
12 pounds

Figure 6-2. Motorola Wideband Telemetry Transmitter

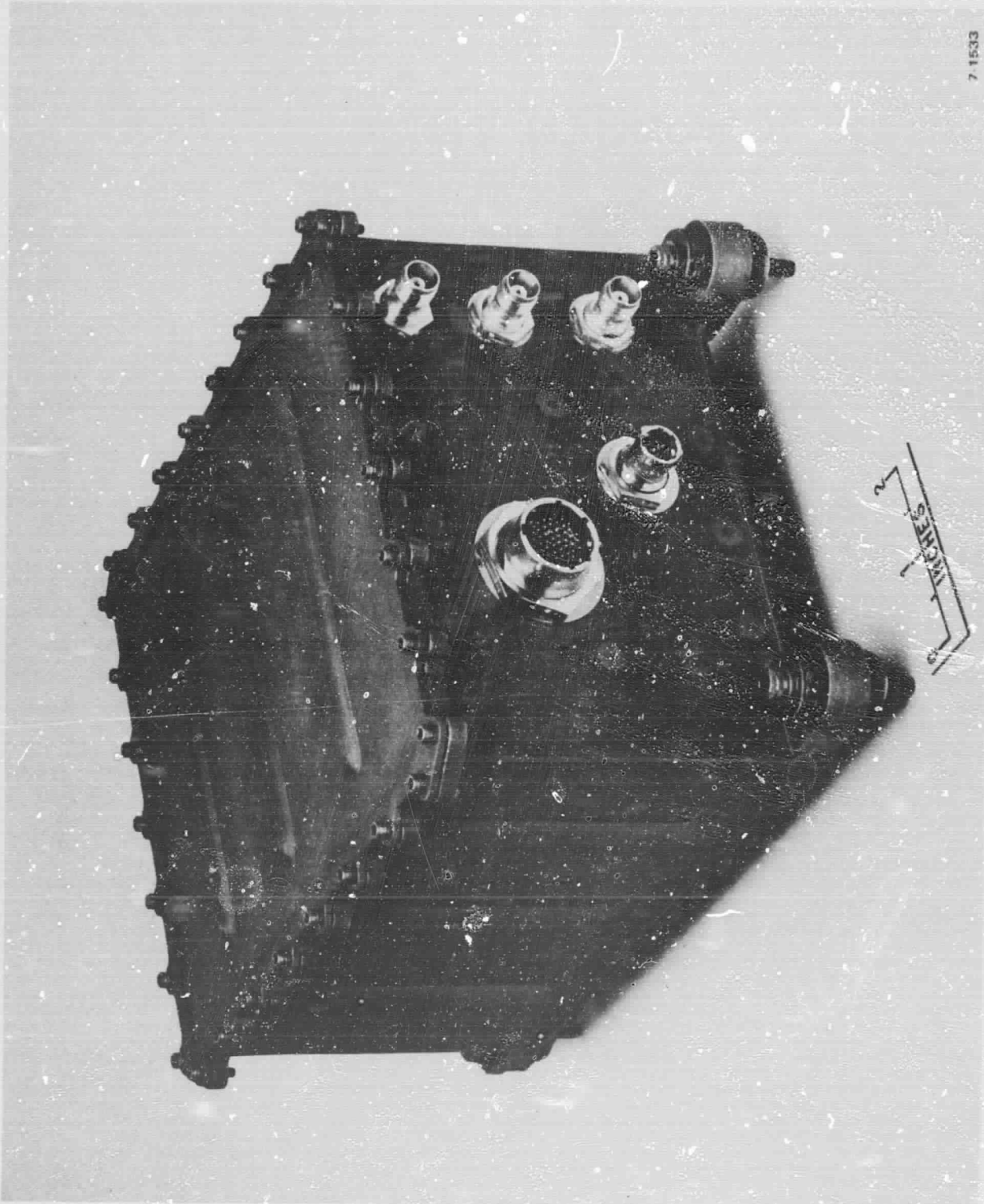


Figure 6-3. Motorola SGLS Receiver

Table 6-2. Basic Cluster Equipment Summary

Figure 6-1 Reference

Unit	Volume (Cu. In)	Weight (Pounds)	DC Power (Watts)
1. Control and Monitor Panel	1120	10.0	20.0
2. Baseband Processor	150	5.0	10.0
3. SGLS Receiver	200	6.0	8.0
4. Wideband Transmitter	432	12.0	120.0
5. RF Latching Switch (2)	2	0.4	0*
6. S-Band Preamplifier	18	1.3	1.2
7. Phase Modulator/Exciter	75	3.6	13.0
8. S-Band Diplexer	21	1.4	0
9. Omni-Antenna (2)	46.4 cu. ft.	43.0	0*
10. Steerable Antenna Subsystem <sup>#</sup>			
a. Reflector and Feed	31 cu. ft	30.0	0
b. Gimbal	50	5.0	0
c. Boom	10 cu. ft.	9.0	0
d. Steering Control	150	5.0	5.0
e. Deployment	360	10.0	0*
11. Cabling		45.0	0
12. Waveguide (Al)	24.3 cu. ft.	44.0	0
13. Mounting Hardware		7.0	0
TOTAL		237.7 pounds	177.2 watts
<sup>#</sup> General Dynamics Design			
*No steady state power required			

Table 6-3. CAT Delay Transponder Performance

<u>Transponder Performance</u>	
Received Frequency	1800.0 MHz
Coherent Receive/Transmit Ratio	205/256
Dynamic Receiver Range	-40 dbm to 127 dbm
Transmitter Frequency	
coherent, noncoherent PM	2247.8 MHz nominal
noncoherent FM	2253.0 MHz nominal
Stability - noncoherent PM	+30 ppm
noncoherent FM	+100 ppm
Phase Stability Short Term (loop bandwidth $2B_L = 200$ cps)	
Coherent	1° rms
Noncoherent	2° rms
R-F Output Power	11.0 watts minimum
Ranging turn around polarity	In phase
Group Delay	2200 ns maximum
Differential Delay (level -40 dbm to -120 dbm)	50 ns p-p
Index	Selectable
EMI	MIL-I-26600A
Environmental Requirements	Compatible with Table 6-5

Table 6-3. CAT Relay Transponder Performance (Cont)

<u>Specific Unit Performance</u>	
<u>Receiver Unit</u>	
Input Impedance	50 ohms
VSWR	1.5:1
Noise Figure (at Rcvr Input, weak signal)	8 db
Dynamic Range	-40 dbm to -126 dbm
Strong Signal Loop Gain (GSS)	$10^9$ /sec
Receiver loop bandwidth ( $2B_{Lo}$ at -127 dbm)	1000 Hz nominal
Acquisition Threshold (90% probability)	-126 dbm
Mean Acquisition Time	3.25 seconds
Maximum doppler tracking rate	200 kHz/sec
Predetection bandwidth	6.5 MHz
Post detection bandwidth (.50 ohms)	2.7 MHz
Coherent reference signal (70 MHz nominal)	0 to 6 dbm
<u>Transmitter Unit</u>	
FM Input Impedance	75 ohms
Modulation bandwidth (3 db)	7 MHz
Sensitivity	20 MHz/volt
Peak deviation capability	10 MHz

Table 6-3. CAT Relay Transponder Performance (Cont)

FM distortion (+4.5 MHz deviation, 100 Hz to 6 MHz input)	Distortion products 30 db down in 5 kHz BW.
Amplitude Modulation	5% maximum
Incidental FM	40 db down at $\pm 6$ MHz deviation
Output Impedance	50 ohms
VSWR	1.3:1 maximum
<u>Phase Modulator/Exciter Unit</u>	
Input Impedance	150 ohms $\pm 10\%$ , 40 pf max
Modulation Bandwidth (3 db)	DC to 10 MHz
Sensitivity	0.6 rad/volt
Peak deviation capability	2.8 radians
Total harmonic distortion	3.0% maximum
Frequency	
Input Reference	70 MHz nominal
Auxiliary Oscillator	70 MHz nominal
Output	560 MHz nominal
R-F Output Power	2 watts

Table 6-4. Baseband Processor Unit Perform

Function	Modulation	Sensitivity	Bandwidth(3db)	Linear
Uplink Data Demodulation Characteristics				
Up-Voice	FM 7.5 kHz pk dev, 30 kHz subcarrier	Compatible with destination	300 Hz-3 kHz at 2 db	Distortion at $\pm 7.5$ kHz deviation
Up-Data	FM 5 kHz pk dev, 70 kHz Subcarrier	Compatible with destination	300 Hz-4 kHz	2% at 5 kHz deviation
Range & Range Rate				
PRN Code	Demodulated PM	1:1 turnaround (referred to system)	815 kHz LP	PRN 0-0.8 rad $\pm 25\%$ 0.8-1.34 $\pm 40\%$
ATSR Tones	Demodulated 4 kHz to 5 MHz tones	1:1 turnaround (referred to system)	815 kHz LP 150 kHz at 5 MHz	ATSR TB
Downlink Modulation				
51.2 kbps PCM	Bi-phase modulation on 1.024 MHz subcarrier	$\pm 90^\circ$ referred to Xmtr	270 kc at 1.024 mc	TBD
Crew Voice	FM/PM, 1.25 MHz subcarrier	SCO 6.8 kHz/vpk Xmtr 0.6 rad/vpk	dc to 125 kHz	0.5% BSL

Table 6-4. Baseband Processor Unit Perform

Function	Modulation	Sensitivity	Bandwidth(3db)	Linear
Uplink Data Demodulation Characteristics				
Up-Voice	FM 7.5 kHz pk dev, 30 kHz subcarrier	Compatible with destination	300 Hz-3 kHz at 2 db	Distortion at $\pm 7.5$ kHz deviation
Up-Data	FM 5 kHz pk dev, 70 kHz Subcarrier	Compatible with destination	300 Hz-4 kHz	2% at 5 kHz deviation
Range & Range Rate				
PRN Code	Demodulated PM	1:1 turnaround (referred to system)	815 kHz LP	PRN 0-0.8 rad $\pm 25\%$ 0.8-1.34 $\pm 40\%$
ATSR Tones	Demodulated 4 kHz to 5 MHz tones	1:1 turnaround (referred to system)	815 kHz LP 150 kHz at 5 MHz	ATSR TB
Downlink Modulation				
51.2 kbps PCM	Bi-phase modulation on 1.024 MHz subcarrier	$\pm 90^\circ$ referred to Xmtr	270 kc at 1.024 mc	TBD
Crew Voice	FM/PM, 1.25 MHz subcarrier	SCO 6.8 kHz/vpk Xmtr 0.6 rad/vpk	dc to 125 kHz	0.5% BSL

Processor Unit Performance

Bandwidth (3db)	Linearity	Level/ Impedance	Processor Characteristics
1 kHz	Distortion 7% at $\pm 7.5$ kHz deviation	TBD, 600 ohms	Limiting 10 db min. S/N (max dev) 35 db min.
1 kHz	2% at 5 kHz deviation	TBD, 600 ohms	Limiting 10 db min. S/N (max dev) 30 db min. Time delay $\pm 20$ usec max.
LP	PRN 0-0.8 rad $\pm 25\%$ 0.8-1.34 rad $\pm 40\%$	Compatible with Phase Modulator	Phase sense positive
LP at	ATSR TBD		Pre-emphasis approx. 20 db at 5 MHz
1 kHz	TBD	0-6v p-p input Input impedance compatible with source.	SCO Stability $\pm 0.007\%$
1 kHz	0.5% BSL	0-5v p-p, balanced 600 ohm input	SCO Stability $\pm 0.2\%$ Limiting at min input 10 db. Clipping 0 db at 1 kHz, 2.2 Vpp.

6-11, 6-12

FOLDOUT FRAME

2

Table 6-4. Baseband Processor Unit F

Function	Modulation	Sensitivity	Bandwidth(3d
Crew Voice (with TV)	FM/FM, 4.5 mc subcarrier	SCO 200 kHz/vpk Xmtr 20 MHz/vpk	300 Hz-5 kHz (2 db)
Voice Backup	PM, direct xmtr carrier modula- tion	1.2 rad/2.5 vpk referred to xmtr	300 Hz-2.3 kHz
TV Video (No pre- emphasis)	FM direct on carrier	18 MHz/vpk referred to xmtr	10 Hz-10 MHz
TV video (pre-emphasis)	FM direct on xmtr carrier	3.92 MHz rms/ Vp-p referred to xmtr	TBD

Processor Unit Performance (Cont)

Bandwidth(3db)	Linearity	Level/ Impedance	Processor Characteristics
0 Hz-5 kHz (3db)	Distortion max 2%	0-5Vpp, bal- anced 600 ohm input)	SCO stability $\pm 0.2\%$
0 Hz-2.3 kHz	7% at 5 kHz deviation	0-5 Vpp, bal- anced 600 ohm input	6 db/octave pre- emphasis. 24 db clipping level.
0 Hz-10 MHz	See xmtr	1Vpp-75 ohms	
D	See xmtr	1V <sub>r</sub> 75 ohms	Pre-emphasis 6 db/ octave

6-13, 6-14

A preliminary block diagram of the Baseband Processor is shown in Figure 6-4. The controllable Baseband functions are mainly summarized by the Control/Monitor Panel Functional Diagram, Figure 6-5. The HI/LO ranging index and PM noncoherent mode switches are not shown in Figure 6-5.

A deployable antenna design under consideration for the omni-antenna application is a helical spiral antenna mounted on top of a Ryan Aeronautics extendible antenna mast shown in Figure 6-6. A mast length of ten feet is assumed to be adequate. The helical spiral antenna is estimated to have 1 db of gain over 50% of a sphere and the losses from the excitation input to the antenna are estimated to be 1.7 db. This information is very preliminary, but is used for the back-up voice mode analysis of paragraph 3.3. During the next program phase, the omni-antenna design should be investigated in more detail in order to select the most efficient unit presently available.

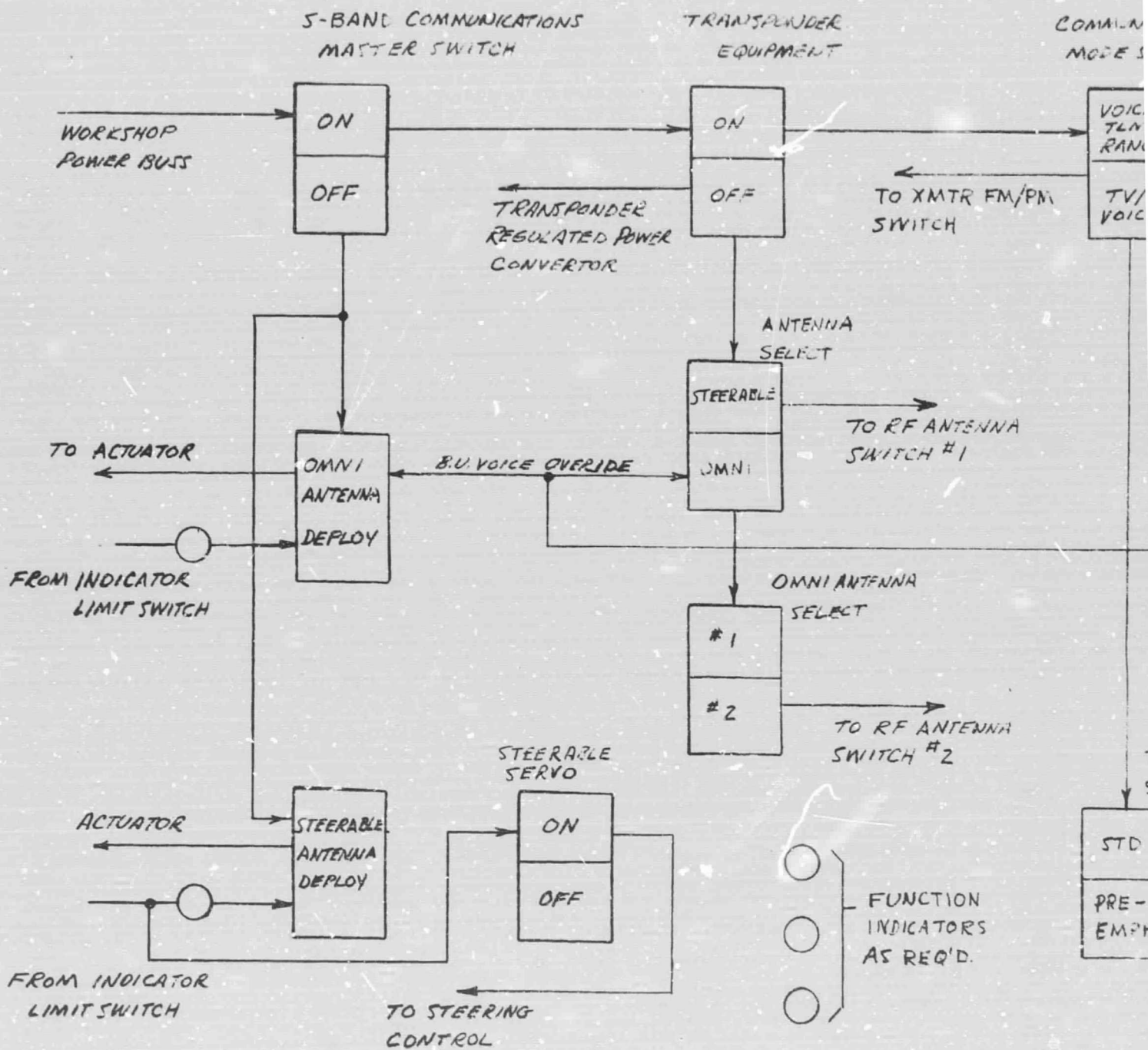
### 6.3 VEHICLE INSTALLATION

The preliminary result of the paragraph 5.3 location tradeoff was to locate the antenna and sensitive units at the aft skirt. Figure 6-7 shows conceptually how this installation could be implemented, the solar panels being parallel to the page. The antenna subsystem shown is the General Dynamics expandable-truss design discussed in paragraph 5.1, however, the TRW thin-film antenna and pole mast can be substituted.

The equipment shown in the Workshop Aft Skirt (interior) section of Figure 6-1 would be mounted on one 15 1/2 x 27 inch honeycombed fiberglass panel which is mounted to the aft skirt with load isolators. The base of the antenna boom will be tethered to the aft skirt stringers at the base of the equipment panel, possibly requiring the bottom of the panel to be notched out. The r-f output power components will be laid out on the panel to minimize r-f losses and allow achievement of the low circuit losses estimated for the previous link calculations. It appears that one or two (one to tether the boom?) panels may be required for the equipment. Recent conversation with Douglas-Huntington Beach, California indicates that presently no panel positions are open in the aft skirt area and therefore some vehicle equipment reorganization would be required to make the proposed installation.

The Phase Modulator, Receiver and Baseband Processor units would be located on a 29 1/2 x 43 inch cold plate panel in the forward skirt area in anticipation of insufficient aft skirt mounting area and convenience of the Baseband Processor to the spacecraft and Control/Monitor interface. The steering control unit is another possible candidate for location forward. The Control/Monitor Panel will be located in the experiment area of the crew quarters.





**NOTES**

- 1) FUNCTIONS TO BE ENERGIZED BY CLOSURE OF SWITCH TO GND RETURN.
- 2) BLOCK  INDICATES PUSHBUTTON SWITCH LIGHTED IN ENERGIZED POSITION.

COMMUNICATIONS  
MODE SELECT

DOWNLINK MODULATION  
CONTROL

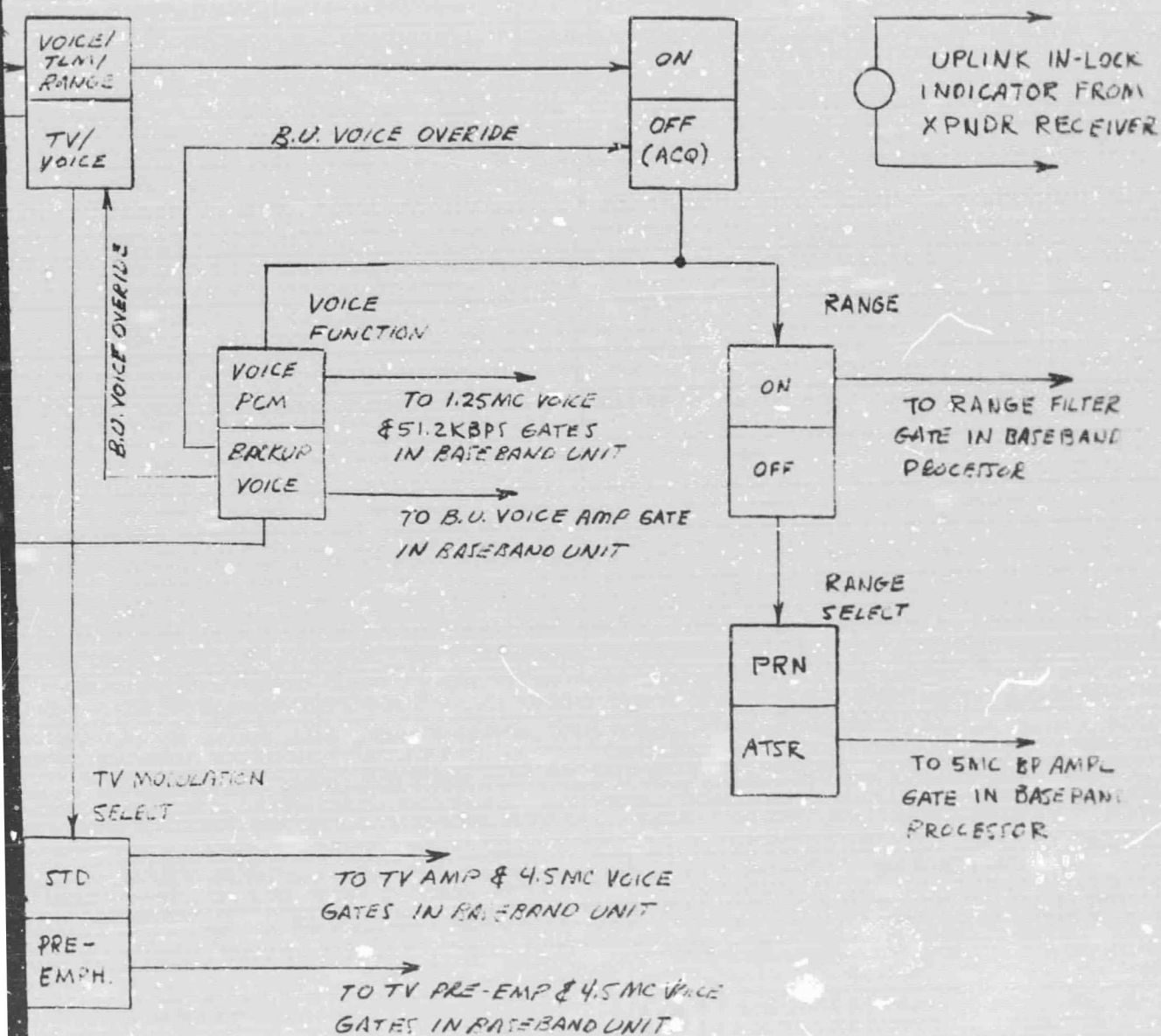


FIGURE 6-5  
FUNCTIONAL DIAGRAM  
CONTROL AND MONITOR UNIT  
COMMUNICATIONS-USE TRACKING RELAY #3503

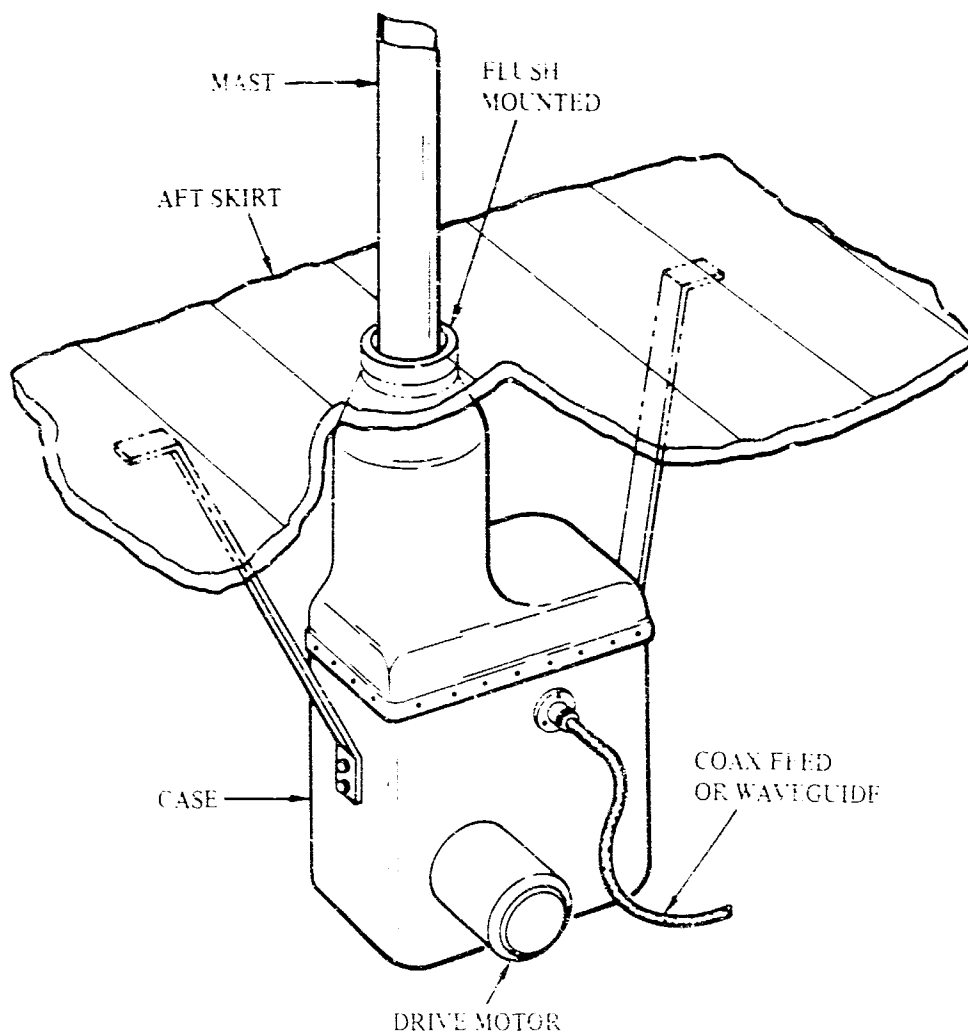


Figure 6-6. Deployable OMNI Antenna

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The omni-antennas must be located as close as possible to the transmitter to conserve power. The obvious choice is near the bottom of the aft skirt where deployment can be made through the exterior skin from a mounting on the skirt interior. The two omni-antennas will be located 180° apart and orthogonal to the solar panels. Waveguide transmission will be used from the r-f switch to the omni's in order to minimize loss.

The anticipated environment for the aft skirt panel is listed in Table 6-5. The vibration levels are at the skirt and do not include the attenuation of the panel mounting isolators. These isolators have a Q of 2.5 to 4 resulting in a typical loaded panel resonance frequency of 35-50 Hz. Although an actual vibration profile incident to the CAT Relay equipment has not been calculated, no vibration problems are expected since the equipment has all been designed for high vibration environments and operational survival only is required during vibration. The most severe thermal problem will occur in the Wide-band Transmitter. With a maximum ambient temperature of 100°F the transmitter will be hard mounted on a metal heatsink installed on top of the fiberglass mounting panel. The 11 watts minimum r-f output power can then be obtained by switching the transmitter power on only during experiment operation in conjunction with the ATS-F. If the ambient temperature actually turns out to be significantly lower than 100°F, continuous transmitter operation could be considered.

The environment in the forward skirt area is not known presently, however, it would be expected to be less than the aft skirt vibration or temperature ranges. The crew quarters temperature environment is relatively mild because of the shirt sleeve working requirements for the crew. Storage of the Control/Monitor unit in the tank when filled with LOX has not been considered or investigated.

Table 6-5. AAC Environment

Aft Skirt Area

Vibration-launch	Hz	Level
a. Sine	5-60	0.05 inch D.A.
	60-200	9.9g peak
	200-295	0.0038 inch D.A.
	295-2000	17.0g peak

Table 6-5. AAC Environment (cont)

b. Random	Bandwidth	Level
	20-85 Hz	0.13g <sup>2</sup> /Hz
	85-280 Hz	6.5 db/octave
	280-1000 Hz	1.6g <sup>2</sup> /Hz
	1000-2000 Hz	-12 db/octave
Temperature-Ambient		
a. Ground location	+120°F	
b. Orbit	+100°F	
Temperature-Structure		
a. Orbit	+100°F	
<u>Forward Skirt Area</u>		
Not known		
<u>Crew Quarters - Experiment Area</u>		
Temperature-Ambient	45°F to 100°F	
Temperature-Wall surface	45°F to 105°F	

## SECTION VII

### 7. CLUSTER TERMINAL ALTERNATIVES

A number of system enhancing alternatives are possible at increased program cost. Most of them have been mentioned in previous sections.

#### 7.1 POTENTIAL ERP INCREASE

Increasing the antenna aperture can rather easily be accomplished since either parabolic reflector is a new design. The limiting factors on ultimate size are pointing error due to AAC attitude uncertainty, required stowable volume, pattern distortion by the solar panels and cost.

Increasing the transmitter r-f power by adding a traveling wave amplifier between the Wideband Transmitter and the Diplexer is readily accommodated. Figure 7-1 demonstrates how such an addition could be accomplished with minimum change to the basic recommended system of Section 6. This high power system has several advantages:

1. R-f switch is eliminated from path to steerable antenna.
2. The Wideband Transmitter can be located on the forward skirt cold rail panels (continuous operation possible) and possibly closer to the omni installations.
3. Fewer units are required to be located adjacent to the steerable antenna to conserve r-f power.
4. The omni receive noise figure can be customized without degrading the steerable antenna uplink. A diplexer and preamp could be located adjacent to each omni antenna.
5. TWT failure does not cause omni transmission link outage.
6. Link margin using steerable antenna is increased by 4 db (see Table 5-4).
7. Higher-power qualified-TWTA, if available, can be substituted with no change to the system cabling or any unit relocation.
8. The r-f power at the omni antenna increases by 0.5 db for the same relative transmitter-antenna location as in the basic recommended system.

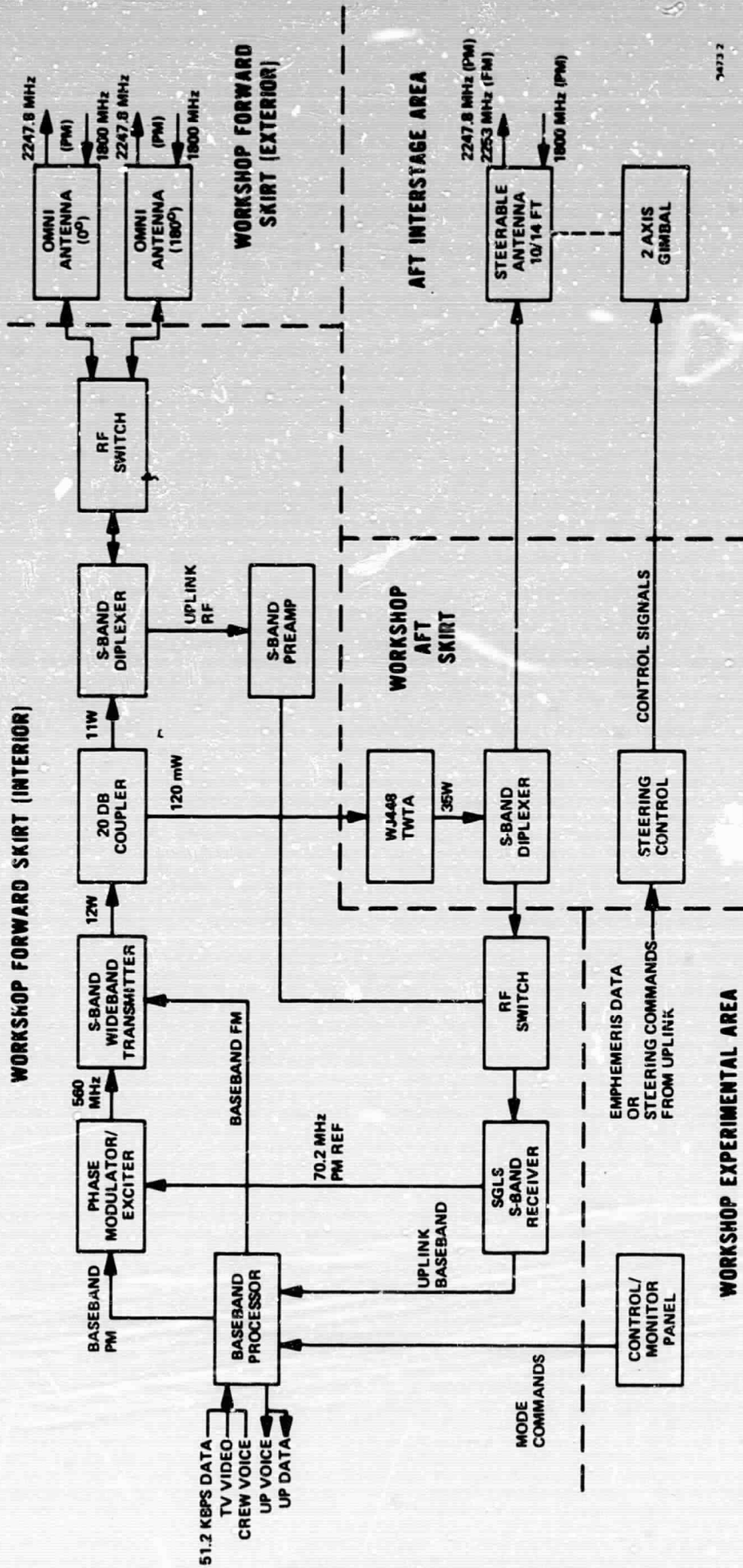


Figure 7-1. High Power CAT Relay Cluster Equipment

The omni uplink service as suggested above could be further improved by installing a low noise preamp at the input port of each antenna. This would also allow use of ferrite switches everywhere. Figure 7-2 shows such an antenna system.

The Watkins Johnson WJ448 35 watt TWT is especially attractive for use since it will be available as a NASA space-qualified amplifier package with integrated power supply in the fall of 1969. Watkins Johnson is presently providing design and qualification of this unit to Saturn V vibration levels on NASA-MSFC contract NAS-8-20787. The qualified unit will weigh 14 to 16 pounds, and have 35.6% overall efficiency at 90°C baseplate temperature. With the output isolator and filter included, the minimum output power will be 35 watts, eliminating these two circuits will yield 40 watts output power.

## 7.2 LINK SERVICE IMPROVEMENTS

Other link improvements which can be accomplished at increased cost include modified receiver capability to receive uplink television (see paragraph 4.5), modulation of the 5 MHz ATSR tone on the FM transmitter at 5 MHz peak deviation, downlink transmission of color television, and the sophistication of the omni back-up voice service by providing simultaneous spherical antenna pattern coverage.

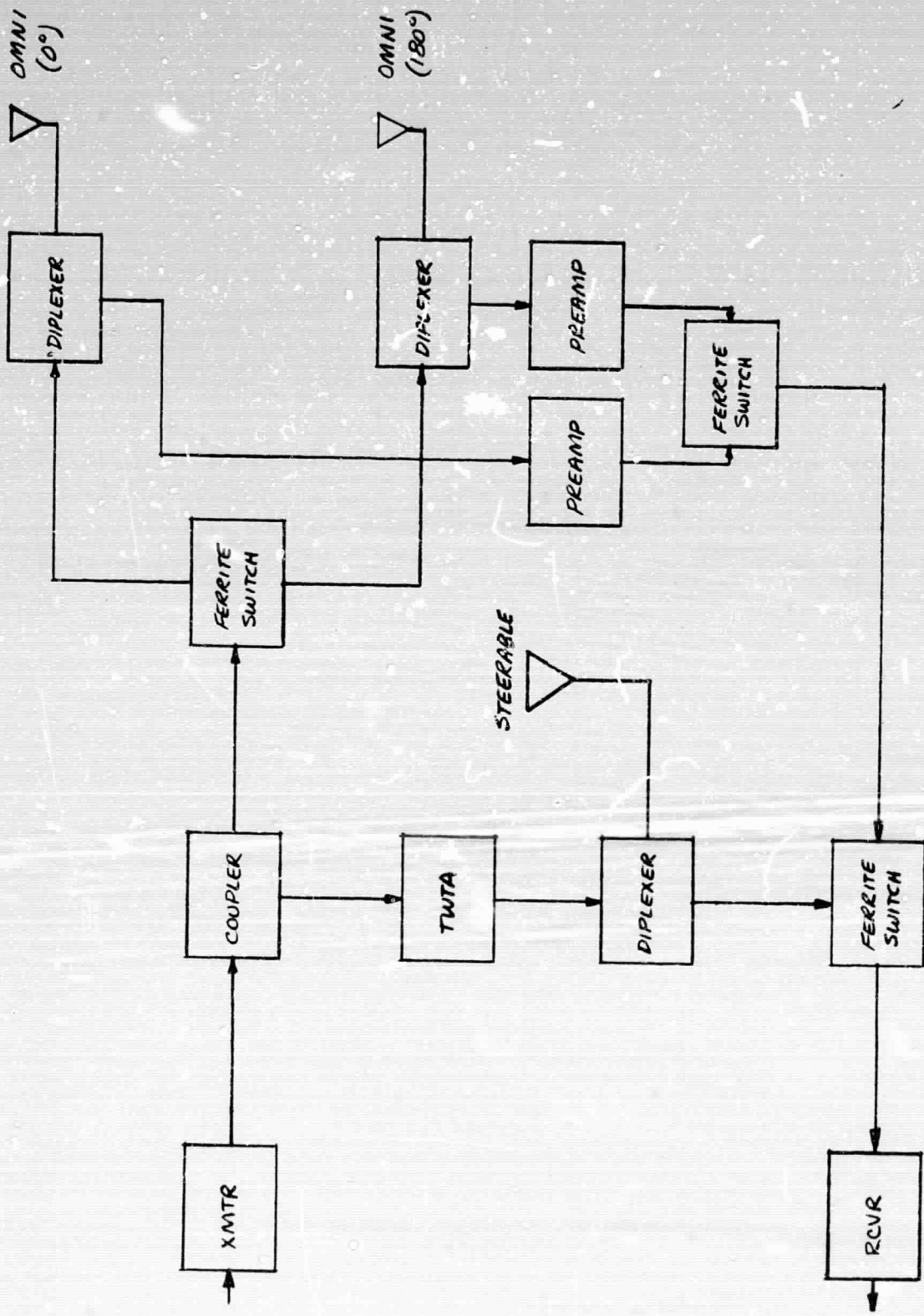


Figure 7-2. Minimum Omni Service Noise Figure - All Ferrite Circulator Switch Configuration

## SECTION VIII

### 8. ATS TERMINALS

This section is a brief description of the necessary increased capability requirements of the ATS-F and ATS Ground Station which are required or desirable for the success of the CAT Relay Experiment.

#### 8.1 ATS-F SATELLITE

In general, the link calculations of Sections 3 and 5 have been made using GSFC S-733-P-15, "ATS-F Spacecraft Performance Requirements, Specification for the Nimbus/AAP Data Relay Experiment", August 1968, specified levels. The following additional capability is required:

1. The ATS-F shall be capable of tracking the AAC ephemeris as defined in Section 2 with not more than 0.5 db pointing error or beam switching ripple in excess of the 3 db scan loss defined in GSFC paragraph 4.1.2.
2. While the ATS-F is tracking the AAC at S-band, the X-band ground link pointing error shall not increase.
3. The repeater translation oscillator short term stability shall not exceed  $5 \times 10^{-10}$ /second in order for the Section 9 range rate analysis to be valid.
4. The minimum S to X-band narrow bandwidth (GSFC 4.7.5) for down-link back-up voice transmission on the noncoherent PM carrier is 245 kHz and for coherent PM relay is 345 kHz.
5. The maximum sideband unbalance contribution of the  $35 \pm 5$  MHz mode for 5 MHz ATSR PM tones shall not exceed 0.1 db when relaying in either direction in order for the Section 9 range rate accuracy analysis to be valid.

It is considered highly desirable to reduce the circuit and scan losses and increase the antenna boresight gain if reasonable. The latest ATS-F specification should be used prior to building CAT Relay equipment to update the link analyses herein. It is also desirable to decrease the X-band acquisition time to ten seconds or less in order to significantly reduce the carrier acquisition time (see paragraph 10.3).

The following understandings are also derived from the ATS-F specification:

1. The AAC nominal received frequency is defined as 1800.0 MHz consistent with GSFC 4.3.1. The AAC coherent transmitted nominal frequency then becomes 2247.80487680 MHz which the ATS-F must be capable of receiving and coherently translate to the X-band downlink frequency.
2. All CAT Relay transmissions except narrowband back-up voice can be effected through common 30 to 40 MHz bandwidth channels for either relay direction through the ATS-F.

## 8.2 ATS GROUND STATION

The Mojave ATS Ground Station has been assumed for the analysis on this program. Any other ground station could be used as long as the X-band link losses are not increased above that recorded in this report and provided the ground station meets the following requirements originally defined for the Mojave station:

1. A Mark I ranging system shall be located at the ATS ground station.
2. A MSFN ground station, preferably in close proximity, shall be utilized for processing both the uplink and downlink subcarrier signals utilizing an intersite communications link at baseband subcarrier frequencies (30 kHz, 70 kHz, 1.024 MHz, 1.25 MHz).
3. The ground station shall have X-band transmit and receive capability at the ATS-F link frequencies as follows:
  - a. Transmit antenna gain - 57 db minimum with zero pointing loss.
  - b. Transmit power - 26.8 dbw at the antenna feed output.
  - c. RCP transmit and receive polarization.
  - d. Receive antenna gain - 56 db minimum with zero pointing loss.
  - e. Receiving system noise temperature of  $100^{\circ}\text{K}$  maximum.
  - f. Receive feed to paramp circuit loss of no more than 0.1 db.
4. The ground station shall be able to interface with the CAT Relay ground equipment and signals as defined in Figure 8-1.

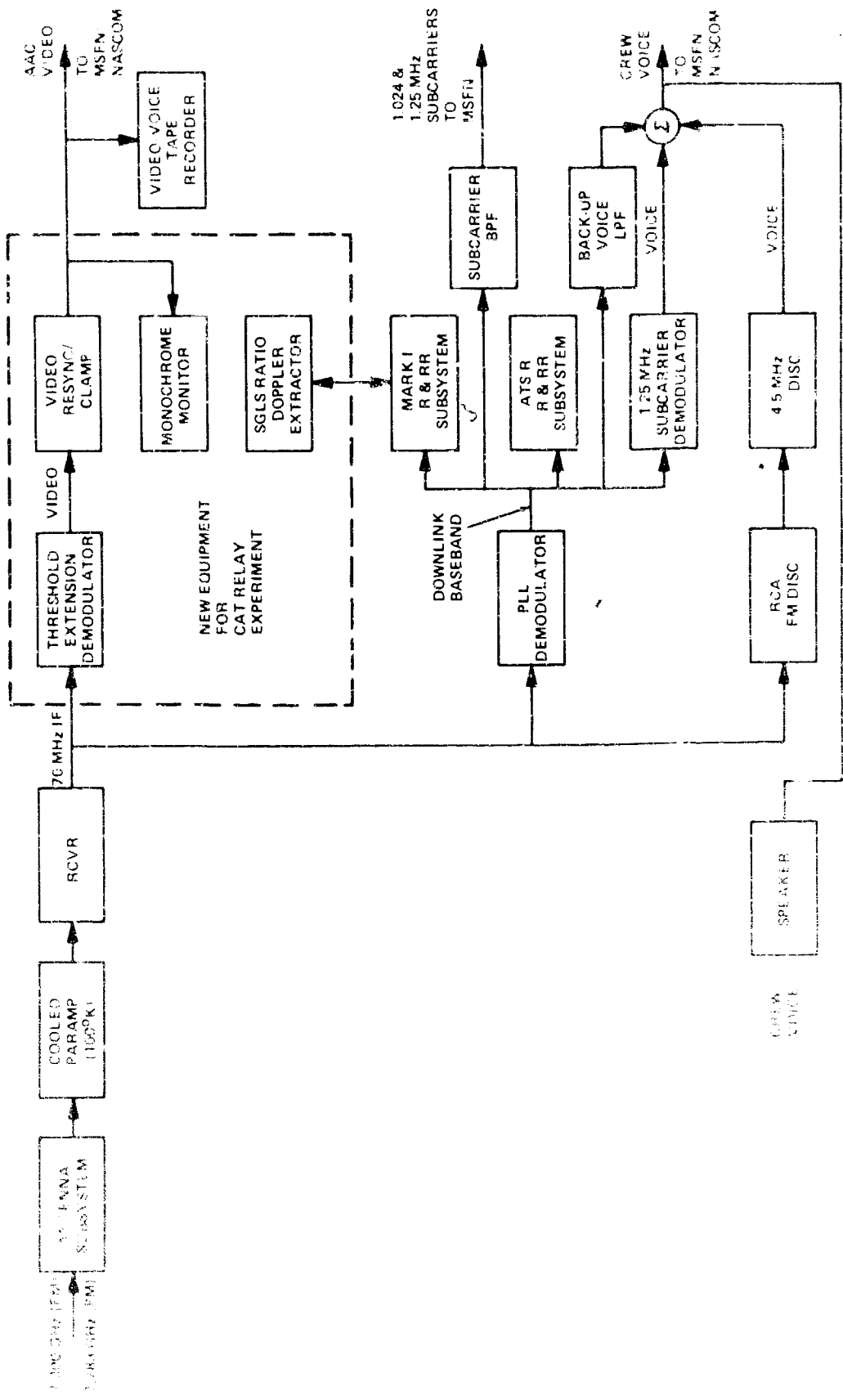


Figure 1. Block diagram of the video and voice processing system.

The receive portion of the ATS ground station is expected to appear as shown in Figure 8-1. The following CAT Relay ground equipment will be furnished for the Experiment.

1. Threshold Extension Demodulator with 6 db threshold.
2. TV sync stripper, backporch clamp, and sync regeneration units.
3. Monochrome TV monitor.
4. SGLS ratio doppler extractor which can be used with the Mark I system.

Supplying a threshold extension demodulator is necessary since it was used as the basis for selecting the recommended basic system with an 11 watt flight transmitter. Availability of a custom Experiment demodulator will allow incorporation of the selectable functions recommended in paragraph 4.2.3 such as de-emphasis in or out, selectable post detection bandwidth from 1 MHz to 10 MHz, predetection bandwidths of 20 or 30 MHz. This unit will also allow use of the existing ground station demodulator for recovering the 4.5 MHz voice channel while the TED may be optimized for 1 and 2 MHz video reception.

The ground station is also assumed to have access to commercial or NASCOM high quality video land lines for received video transmission and a video tape recorder. Interfacing equipment which is not available for any of the ground equipment interfaces required would be supplied by the CAT Relay Experiment contractor.

Again an updating of the link calculations should be required after ground station capability has been completely specified.

## SECTION IX

### 9. RANGE AND RANGE RATE MODES

#### 9.1 METRIC ERROR ANALYSIS

For measurement of range and range rate of the Apollo Applications Cluster (AAC) target vehicle, two methods are possible provided that proper modification can be made to the Experiment equipment to make them compatible with Experiment requirements. These two methods are the ATSR system as described in NASA GSFC Report R-65-013<sup>9.1</sup> and the MSFN type of ranging using PRN. Of the two systems, the ATSR looks the most attractive from the ground equipment modification as well as the ATS-F relay configuration requirements. An error analysis using ATSR for this experiment was possible due to the availability of a detailed error budget on the ATSR system. A similar error budget was not available for the MSFN system to provide a valid prediction basis for the metric performance using the ATS-F relay. A further unknown factor in the MSFN system is the contribution to the range rate error that will be introduced by the yet undesigned ground system range rate extractor that would have to be used with the MSFN system. For the PRN-coherent carrier doppler extraction scheme, only guidelines will be given to assure usable operation if that system is pursued to measure range and range rate of the AAC.

##### 9.1.1 ATSR System

The ATSR range and range rate system utilizes a combination of range tones spaced at half decade intervals with 500 kHz the highest range tone used and a range rate tone at 5 MHz. The range is measured by comparing the phase difference between the transmitted 500 kHz tone with the received 500 kHz tone. The cycle ambiguity is resolved by comparing phases of lower frequency ambiguity tones. Outside of resolving the ambiguity, the lower frequency tones do not contribute to the range error. The range reading does depend upon the phase of the highest range tone so that the behavior of the phase function of the system in the vicinity of the highest range tone is the only portion pertinent to the range error. This is in direct contrast to the PRN type of ranging wherein the error involves the weighted group delay across the spectrum.

A major advantage of the ATSR is that measurement of range rate does not require a coherent carrier system and special system peculiar doppler extraction equipment. This is accomplished by measuring the doppler on a high frequency side tone modulated on the carrier. This side tone is at 5 MHz

providing system capability exists to pass this high of a tone frequency. Otherwise, the highest range tone (500 kHz) is used to determine doppler with greatly deteriorated performance. With a CAT Relay Experiment goal of 3 cm/sec accuracy for the range rate measurement, the use of the 5 MHz tone is indicated providing it is compatible with the Experiment equipment. The bandwidths of the ATS-F relay repeater and ground equipments can be chosen wide enough so that the only band restricting block in the system is the transponder in the Cluster target vehicle. Measurements were made on the Motorola transponder which indicated that with an addition of a band-pass filter centered at 5 MHz shunting the existing ranging low pass filter, the transponder could turn around the 5 MHz range rate tone. The detailed range and range rate error analysis involves using the 5 MHz range rate tone. Since detailed equipment performance is not available for operations utilizing the 500 kHz tone for range rate measurements, an estimate is made of the measurement accuracy by considering the error sources to increase in inverse ratio to the range rate tone frequency.<sup>9.1</sup>

#### 9.1.1.1 ATSR System Metric Error Analysis

The error analysis is based upon the system parameters listed in Table 9-1. This analysis was performed prior to final CAT Relay Experiment signal to noise density calculations and has not been updated. Thermal noise error contributions, however, are not the major contributing errors.

Table 9-1. ATSR System Parameters

#### ATS Mojave Ground Station

Carrier Loop Noise BW ( $2B_n$ )	200 Hz
5 MHz Range Rate Loop Noise BW ( $2B_n$ )	5.2 Hz
500 kHz Range Tone Loop Noise BW ( $2B_n$ )	1.0 Hz
5 MHz Modulation Index	1.2 rad.
500 kHz Modulation Index	.5 rad.
Sampling Rate	1/sec

#### ATS-F Relay

Receiver BW	
X-Band	10 MHz
S-Band	5.5 MHz
Coherent Carrier Loop BW	500 Hz

Table 9-1. ATSR System Parameters (cont)

Translation Oscillator Short Term Stability	$5 \times 10^{-10}$ /sec
<u>AAP Cluster</u>	
Receiver BW	
Predetection	6 MHz
Post Detection	
Low Pass Section	800 kHz
5 MHz Bandpass	150 kHz
<u>Path Signal to Noise Densities</u>	
Ground to ATS-F	102.2 db - Hz
ATS-F to Ground	91.5 db - Hz
ATS-F to AAP Cluster	75.6 db - Hz
AAP Cluster to ATS-F	84.3 db - Hz
<u>Signal Dynamics</u>	
ATS-F - Ground Path	No dynamics
ATS-F - AAP Cluster Path	
One Way Velocity	7225 m/sec
One Way Acceleration	9.15 m/sec
5 MHz Two Way Doppler	241 Hz
5 MHz Two Way Doppler Rate	0.305 Hz/sec

#### 9.1.1.2 Error Analysis of Range Rate

The range rate instrumental accuracy is limited by noise errors composed of the resolution errors and additive input noise.

9.1.1.2.1 Resolution Errors. The resolution errors define the limitations of the metric system operating with infinitely high input S/N ratios. These errors may be considered to be time-measurement jitter errors. The range rate error caused by a timing error is given by

$$\sigma \dot{R} = \frac{(C)(m) (f_b + f_d (\max) )^2}{2 f_t N} \sigma T$$

where

$$f_b = 1 \text{ kHz/sec}$$

$$f_d = 241 \text{ Hz}$$

$$m = 100$$

$$N = 6400 \text{ for } 8/\text{sec}$$

$$N = 8 \times 6400 \text{ for } 1/\text{sec}$$

$$f_t = 5 \times 10^6 \text{ Hz}$$

$\sigma T$  = Time Error

The timing error is made up from the following sources:

1. Quantization Error
2. Analog/Digital Conversion Error
3. Time Base Reference Jitter
4. Reference Oscillator Short-Term Instability
5. Range Rate Tracking Oscillator Short-Term Instability

Using the parameters listed in this report, the following errors will exist.

	<u>Sample Rate</u>	
	8/sec	1/sec
Quantization	.003 m/s	.00037 m/s
Analog/Digital	.0062	.00078
Time Base Jitter	.0031	.00039
Oscillator Short-Term Instability		
Transmitter Ref	.0032	.0011
RR VCXO	.03	.0063
Doppler Bias	.0044	.00055

	<u>Sample Rate</u>	
	8/sec	1/sec
Multiplier VCXO	.000196	-
Total rms Resolution Errors	.0314 m/s	.00649 m/s

9.1.1.2.2 Input Noise Errors. When the range rate tone is modulated on a noisy carrier or the total spectrum is translated in frequency by a noisy translation source, angle noise can be impressed upon the range rate tone if the tone sidebands are unsymmetrical. The amount of angle noise modulated on the side tone is proportional to the untracked phase noise in the receiver carrier loop multiplied by a coupling coefficient dependent upon the sideband amplitude unbalance. For 10% unbalance this coefficient is 5% or -26 db. Since the AAP Cluster transponder demodulates the signal and remodulates it, there are two sources where the unbalance adds noise to the tone output, namely in the AAP Cluster transponder and in the ATSR receiver. A maximum sideband unbalance of 10% is expected in both directions. The resultant total noise out of the range rate tone loop is determined by combining the transfer functions of all loops and multiplying this function by the spectral density of noise and integrating the results.

The elements which can contribute to the range rate error are:

1. Communication transmitter frequency synthesizer.
2. Communication receiver microwave local oscillator.
3. ATS-F translation oscillator thermal noise jitter.
4. ATS-F translation oscillator short-term instability.
5. AAP Cluster carrier loop noise.
6. Carrier tracking VCXO in the ATSR receiver.

Using system parameters listed, the following errors may be expected.

	<u>8/sec</u>	<u>1/sec</u>
Communication Transmitter Synthesizer	.00005 m/s	-
Communication Receiver LO	.00005	-
ATS-F Translation Oscillator Thermal Noise	$1.25 \times 10^{-5}$	-
ATS-F Translation Oscillator Short Term	.0664	.0083 m/s

	<u>8/sec</u>	<u>1/sec</u>
AAP-Cluster Carrier Loop Noise	.0018	.00023
Carrier Tracking VCXO Instability	.0071	.0009
RSS Total	.067 m/s	.0084 m/s

From Develet<sup>9.2</sup> the normalized range rate error due to receiver noise is

$$\beta = \frac{R_{\text{rms}} \omega_o}{C \omega_n} (2 S/N)^{1/2}$$

$\beta$  = Normalized Range Rate Error

$\omega_o$  = Transmitted Radian Frequency

$\omega_n$  = Undamped second order phase lock loop natural frequency  
in rad/sec  $\left[ \sqrt{\frac{8}{9} (2\beta_{LO})} \right]$

$$C = 3 \times 10^8 \text{ meters/sec}$$

S/N = signal to noise in loop

In Develet's article,  $\beta$  is plotted against the product  $\omega_n T$  where T is the cycle counting time. For  $2\beta_{LO} = 5.3 \text{ Hz}$  and  $T = .051 \text{ sec}$  for 3/sec and 0.409 for 1/sec data rate, the corresponding  $\beta$  from Develet's curves are: 2.5 and 0.38. This yields a noise error of

$$\begin{aligned} \text{Tone loop noise error} &= \frac{32.5}{\sqrt{S/N}} \text{ m/s for 8/sec rate,} \\ &= \frac{12}{\sqrt{S/N}} \text{ m/s for 1 sec rate} \end{aligned}$$

These can be related to S/KT by including the modulation loss and bandwidth of the loop. Thus for 1.2 radian R tone index and 0.5 radian R tone index with the 5.2 Hz bandwidth loop, we have for a net S/KT of 75 db - Hz:

	8/sec	1/sec
Tone Loop Noise Error	.022 m/s	.00338 m/s

9.1.1.2.3 Total Range Rate Errors. The total error is estimated as follows:

	<u>8/sec</u>	<u>1/sec</u>
Resolution Errors	.0314	.0065
Unbalance Sideband Errors	.067	.0084
Thermal Noise	.022	.0034
Total	.077 m/s	.011 m/s

The estimated error using the 500 kHz tone for range rate will be 10 times worse than the above errors calculated for the 5 MHz tone.

### 9.1.1.3 Error Analysis of Range

The ATSR equipment will be operating in Mode 2 with 5.2 Hz bandwidth. The range errors can be grouped into resolution and instrumental errors. A summary of the resolution error taken from the ATSR design report is as follows.

#### 9.1.1.3.1 Random Errors. (Source ATSR-R-65-013).

##### Start Pulse

Reference Range Tone Jitter	0.45 meters
Axis Crossing Detector	0.15

##### Stop Pulse

Reference Range Tone Jitter	0.45
Modulator	0.3
Carrier Receiver/Demodulator	-
5 MHz VCXO	-
Axis Crossing Detector	0.3
Digital Division	0.3

Quantizing 0.61

##### Time Base Jitter

Reference Oscillator	-
Synthesizer	0.63

Total RSS 1.21 meters

9.1.1.3.2 Systematic Errors (Source ATSR-R-65-013)

Axis-Crossing Detector	0.15
Side Tone Combiner and Zero Set	
Phase Shifter	0.15
Modulator	0.15
Receiver/Demodulator	0.53
Predetection Filter	
Dynamic	6.9
Temperature	0.58
Tracking Loop Lag	1.05
Time Base	-
Total RSS	7.1 meters

9.1.1.3.3 Noise Errors. The noise errors are based on a total path S/KT of 75 db - Hz, a modulation index for 5 MHz of 1.2 radians and a 500 kHz range tone index of 0.5 radian and using a 5.2 Hz tone loop noise bandwidth. The noise error using this mode is 0.082 meters.

9.1.1.3.4 External Equipment Systematic Errors.

		<u>Source</u>
Communications Receiver	0.53 meter	ATSR-R-65-013 (Ref 9.1)
Communications Transmitter	0.53	ATSR-R-65-013 (Ref 9.1)
ATS-F Transponder (1/2 pp ripple)	1.35	ATS-Spacecraft PRS GSFC S-733-P15 (Ref. 9.3)
SGLS Transponder (40 <sup>o</sup> F to 105 <sup>o</sup> F)	1.65	Test Report Pro- gram 770 Motorola 3330-131-5 (Ref. 9.4)
Total RSS	2.26 meters	

### 9.1.1.3.5 Total ATSR Range Error Summary

Random Errors	1.21 meters
Systematic Errors	7.1
External Equipment	2.26
Noise Errors	0.082
Total RSS	7.5 meters

### 9.1.2 MSFN System

Due to the changed turn around ratios in the relay and transponder equipment only parts of the existing MSFN could be used. Use of the PRN ranging code will require interfacing with the MSFN range receiver unit with an i-f of 10 MHz. This will require furnishing the range receiver with the received code modulated on 10 MHz plus a 10 MHz reference signal. A further consideration involved is a requirement of furnishing an r-f doppler input coherent with the ranging in order to obtain range readings with quantization of less than 1/4 clock period. Since the turn around ratio is different than used on the USBE, a completely new doppler extractor must be designed. Since a major portion of the total doppler error is contributed by the doppler extractor, a meaningful error analysis cannot be made at this time. For an estimate of the error, it may be noted that compared to the ATSR calculations the unbalance sideband errors would be eliminated, the thermal noise error would be reduced, resolution errors would remain approximately unchanged while repeater translation oscillator instabilities would produce a much larger error. By basing an estimate of the doppler error on the range rate error calculated for the Goddard Range and Range Rate System, one would expect the error to be approximately 0.05 m/s for an 8/sec data rate and to be less than 0.01 m/s for a 1/sec data rate.

#### 9.1.2.1 Range Error Analysis

A complete range error analysis using the PRN ranging subsystem of the MSFN station is not possible at this time due to incompleteness of available data and uncertainty of the method of interface with the ATS ground station. However, some data is available <sup>9.5</sup> and these measured errors are listed below.

	<u>Mode</u>	<u>Info</u>	<u>Mod Index</u>
Up PM Mode	2	PRN	1.34 radians
Up PM Mode	6	PRN	0.5
		VOICE	1.00
		DATA	0.76

	<u>Mode</u>	<u>Info</u>	<u>Mode Index</u>
Down F M Mode	2	PRN	1.34 radians (1/1 turn around ratio)
Down PM Mode	4	PRN	0.5
		VOICE	0.7
		PCM	1.2

Two modes are considered, one with PRN only and the other with PRN, VOICE, and DATA in both directions. Since the transponder turns around the uplink subcarriers also, the downlink contains four subcarriers plus the PRN. The modulation loss for the uplink PRN is 12.9 db and for the downlink is 17.6 db for the all services mode of operation. For PRN only, the modulation loss for the code is 2.6 db. The path loss variation will be 2 db so that the range of signal level for the PRN is 17 db. Over this range of signal level the measured delay variation of the range receiver is less than 4 nanoseconds. The measured variation of delay with doppler is approximately 1.0 ns/kHz. Although no specific information is available on other error sources, it is felt that they would be at least equal to the numbers calculated for the ATSR system. One exception, however, is in the ATS-F translation repeater where the delay variation should be less than the peak to peak ripple variation. The delay through the repeater is a weighted function of the total bandwidth delay. Estimating this figure as half of the total delay ripple, a composite of the total error estimation is listed below.

		<u>Source</u>
Random Errors	1.2 meters	Estimated
Systematic Errors		
Dynamic (105 kHz Doppler)	15.7 meters	Task I Final Report (Ref. 9.5)
Signal Variation	0.6 meter	Task I Final Report (Ref. 9.5)
External Equipment		
Transmitter and Receiver	0.75 meter	Estimated
ATS-F Transponder	0.65 meter	Estimated
SGLS Transponder	1.65 meters	Test Report Program 770 (Ref. 9.4)

### Summary

Estimated Resolution Error Without Doppler Correction	15.9 meters
Estimated Error With Doppler Correction	5.5 meters
Noise Errors ( $2B_L = 12$ Hz)	
PRN + Subcarriers	0.1 meter
PRN Only	- - -
Total Uncorrected Range Error	15.9 meters
Corrected for Doppler (estimated)	5.5 meters

## 9.2 ACQUISITION TIME

The acquisition times for the two range tracking methods have been calculated to be as presented below:

### 9.2.1 ATSR Ranging Sidetone Frequency Method

<u>Function</u>	<u>Reference</u>	<u>Time</u>
A) Carrier Acquisition		
1. AT-S-F Relay Receiver	9.3	60.000 seconds
2. AAC Receiver	9.4	3.250 seconds
3. ATSR System	9.1	20.000 seconds
4. Signal Travel Time	Calc	<u>0.473 second</u>
Total		83.723 seconds
B) Sidetone Frequencies		
1. 5 MHz	9.1, 9.6	0.0156 second
2. 500 kHz	9.1, 9.6	0.2560 second
3. Minor Tones (7)	9.1	<u>2.6250 seconds</u>
Total		2.897 seconds

Thus the total acquisition time is equal to 86.620 seconds.

### 9.2.2 MSFN PRN Ranging Code Method

<u>Function</u>	<u>Reference</u>	<u>Time</u>
A) Carrier Acquisition (Assumed to be the same as above)		83.723 seconds
B) PRN Code		
1. Clock (Assumed to be manual)		2.00 seconds
2. Code Components		
S, A, B, C	9.5	<u>3.20 seconds</u>
Total		5.20 seconds

Thus the total acquisition time is equal to 88.923 seconds.

#### REFERENCES

- 9.1 ATSR Design Evaluation Report R-65-013, Prepared for Goddard Space Flight Center by General Dynamics Electronics.
- 9.2 Develet, J. A. Jr. "Accuracy Limitations in a Two-Way Coherent Doppler Measurement System," IRE Transmission - PGSET, Sept. 1961.
- 9.3 ATSF Spacecraft Performance Requirements Specification for the Nimbus/AAP Data Relay Experiment, GSFC S-733-P-15, August 1968.
- 9.4 Vehicle SGLS Engineering Model Test Report 3330-131-5, 770 Program, November 21, 1967, Motorola, Inc.
- 9.5 Task I - Final Report, Apollo USBE Block I Compatibility Test Program, WF 2996-23, Contract NAS9-2563 prepared for NASA/ MSC by Motorola, Inc.
- 9.6 "Analysis and Design of Phase Lock Loops" by Kenneth Wood, ASU, 1962.

## SECTION X

### 10. LABORATORY DEMONSTRATIONS

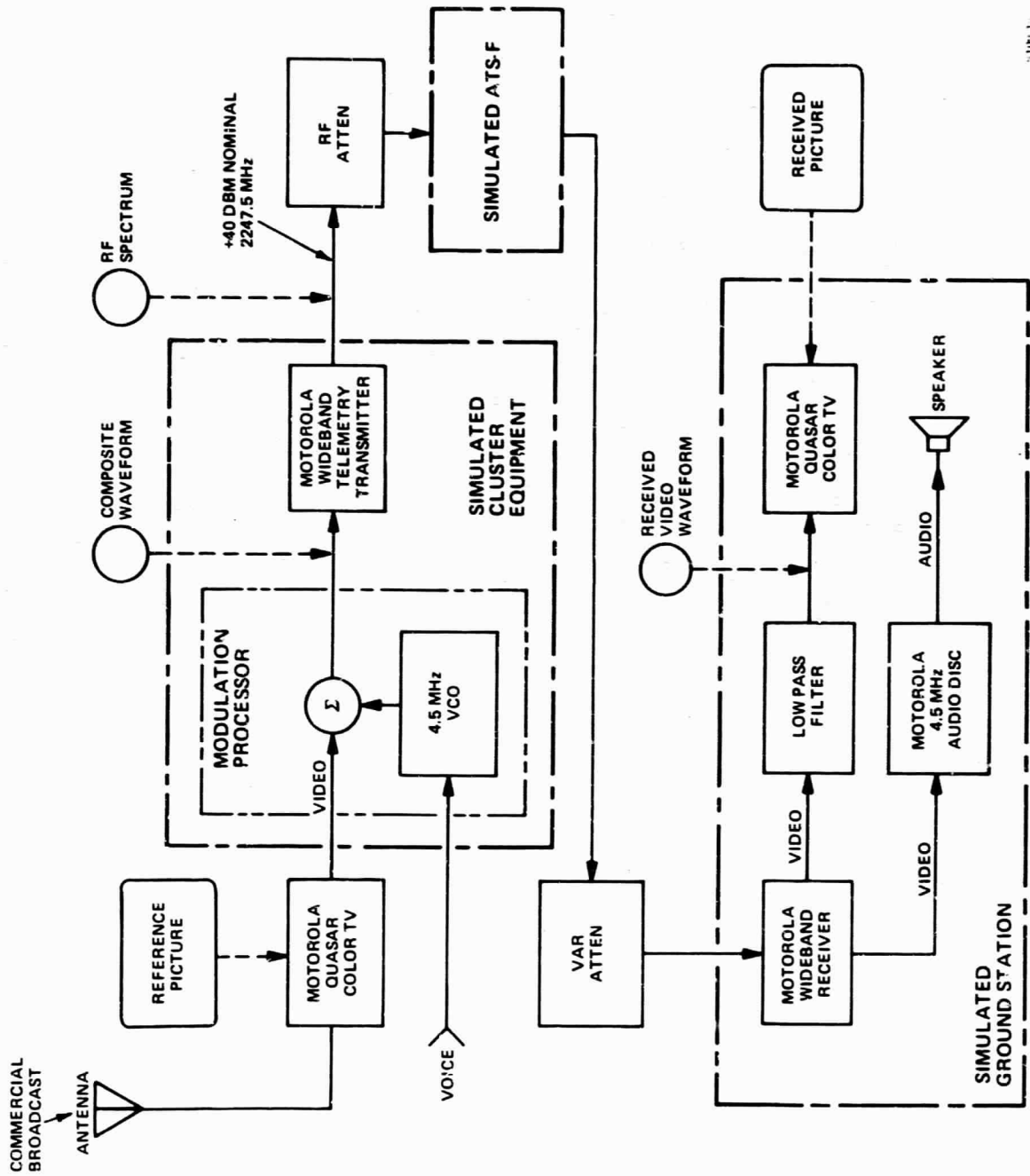
One of the major tasks of this program was to provide a laboratory simulation of the TV/Voice downlink system for a feasibility demonstration to NASA personnel. The result of this effort was a completely successful laboratory demonstration of the recommended CAT Relay System and was given on several occasions using the laboratory system previously described in Section 4.

#### 10.1 DEMONSTRATION SUMMARY

The laboratory/demonstration system was set up as pictured in Figure 4-4 and as detailed in Figure 4-3. The Wideband Transmitter system, shown in simplified form in Figure 10-1, was used for the majority of the demonstrated characteristics. The standard operating conditions listed in Table 4-1 were used throughout the demonstrations. An explanatory brochure entitled "Television/Audio Link Demonstration, NASA Communications and Tracking Relay Experiment" (reference 10.1) was published by Motorola on this contract and distributed to all demonstration viewers. The demonstrations were conducted using live commercial network programming and lasted between one-half to one and one-half hours depending on the details covered.

Demonstrations of the simulated CAT Relay System were viewed by the following NASA and associated personnel:

	<u>Name</u>	<u>Agency</u>	<u>Date</u>
1.	Sam Fordyce	NASA-HQ	10-7-68
2.	Bob Seldon	Bellcomm	10-7-68
3.	Greg Andrus	NASA-HQ	10-16-68
4.	Dr. M. Vacaro	NASA-GSFC	10-18-68
5.	Bob Owens	NASA-GSFC	10-18-68
6.	A. Covington	NASA-GSFC	10-18-68
7.	Jack McClanahan	NASA-HQ	10-31-68
8.	Rudy Rusnak	NASA-MSD	10-31-68



STEP 11

Figure 10-1. Wideband Transmitter Demonstration FM TV/Voice System

<u>Name</u>	<u>Agency</u>	<u>Date</u>
9. John Painter	NASA-Langley	11-8-68
10. Bob Chen	Bellcomm	11-22-68
11. S. Ramji	Communications & Systems, Inc.	11-27-68
12. Hal Hornby	NASA-AMES	12-6-68

On several other occasions, the demonstration was witnessed by Motorola engineering personnel in order to accumulate statistical survey data.

The demonstrations generally included the following material:

1. CAT Relay Experiment Fundamentals.
2. Picture quality survey on monochrome SNR and emphasis effects (see paragraph 10.2)
3. Explanation of the recommended CAT Relay System design and equipment.
4. Demonstration of various system operating alternatives using the Wideband Transmitter system.
  - a. Picture quality at 10 db CNR (originally specified minimum experiment quality) see Figure 4-14, top.
  - b. Monochrome picture quality over 0 to 14 db CNR-see Figure 4-15, 4-16 top for some of these, also Figure 14, page 24 in reference 10.1
  - c. Strong signal picture resolution versus 250 kHz to 10 MHz post detection bandwidth for monochrome (see Figure 4-17) and color.
  - d. Voice link quality over 6 to 14 db CNR range.
  - e. Color picture quality versus the use of emphasis over 10-20 db CNR (see Table 4-2).
5. In some of the earliest demonstrations the following operating performance was included:
  - a. Color and monochrome transmission over the SGLS Transmitter system (block diagram - Figure 4-2).
  - b. Group delay distortion effects on monochrome and color transmission.

- c. Phase modulated monochrome television transmission over a modified simulation of the CAT Relay uplink (see paragraph 4.5)

In summary, it is felt that the feasibility and many of the operating alternatives applicable to the CAT Relay Experiment and Motorola recommended system implementation (see Section 6) have been successfully demonstrated.

## 10.2 Survey Results

The CAT Relay System is being designed as an experiment and not a Comsat type operational television relay. As pointed out in Section 3, very little information or agreement exists on the bare minimum requirements for such an experimental link. It was therefore decided to conduct opinion surveys among engineering personnel in order to determine the minimum picture quality applicable to the CAT Relay Experiment.

Two audience participation surveys were conducted during the demonstrations but prior to any indication of the minimum CNR design for the CAT Relay Experiment. These surveys were conducted using the survey form shown in Figure 10-2. The first survey involved picture quality as a function of predetection CNR (and therefore postdetection SNR) and the second involved picture quality versus the use of FM emphasis. The viewers were mostly engineers or engineering management and represent a wide cross section of people from both within Motorola and from external engineering companies.

The quality survey is patterned after the TASO<sup>10.2</sup> surveys with six quality level definitions. Live commercial pictures at various SNR were transmitted across the simulated link and shown on the Motorola Quasar 23 inch screen for 5 to 10 seconds. Viewers who were 10 to 20 feet away recorded their opinions. The random CNR pattern used for the fifteen survey tests are listed near the bottom of Figure 10-2. All tests were at 9 MHz peak deviation, 2 MHz post detection bandwidth, and no FM emphasis. Approximately 90 people participated in the survey and the compiled results are given in Table 10-1. It is estimated that the CNR resetability for all demonstrations was  $\pm 1$  db. The SNR levels listed in Table 10-1 were taken from the Figure 4-8 system calibration characteristic. It is interesting to note that at least 64 % of all viewers considered TV pictures at 40 db weighted SNR and better to be excellent or fine quality as defined in Figure 10-2.

The use of standard<sup>10.3</sup> FM pre-emphasis/de-emphasis was evaluated by collecting opinions of the apparent improvement/degradation of the four CNR situations listed at the bottom of Figure 10-2. The same conditions

CNR IN 200 HZ BW	14	12	10	8	6	4	2	0	DB
	(S+N)/N RMS/RMS	37.7	35.7	33.5	30.4	25.6	19.5	15.8	
(S+N) WTD P-P/RMS	33.7	51.9	49.4	45.5	39.7	32.8	28.5	25.8	DB
QUALITY	← ABOVE RECEIVER THRESHOLD →				← BELOW RECEIVER THRESHOLD →				
EXCELLENT	82%	76%	51%	37%	—	2%	—	—	% OF TOTAL OPINIONS PER LEVEL
FINE	18%	24%	42%	40%	64%	17%	—	—	
PASSABLE	—	—	6%	19%	22%	35%	10%	2%	
MARGINAL	—	—	1%	4%	12%	37%	48%	21%	
INFERIOR	—	—	—	—	2%	9%	38%	63%	
UNUSABLE	—	—	—	—	—	—	4%	14%	
TOTAL OPINIONS	65	151	175	79	127	181	266	179	

BHM  
2/16/68

Table 10-1. Results of TV Quality Opinion Survey

Figure 10-2.  
 Television Picture Quality Survey Form  
 CAT Relay Demonstration TV Picture Quality Survey

Record your first impression of the picture quality as defined by circling the appropriate test number. The picture SNR will be changed for each test in a random fashion including repeated levels. The baseband bandwidth (horizontal resolution) is fixed for all tests.

NOTE: All quality levels as listed may not be demonstrated.

**EXCELLENT** - The picture is of extremely high quality, as good as could be desired.

Test 1 2 3 4 5      6 7 8 9 10      11 12 13 14 15

**FINE** - The picture is of high quality providing very good NASA technical information. Noise is perceptible.

Test 1 2 3 4 5      6 7 8 9 10      11 12 13 14 15

**PASSABLE** - The picture is of acceptable quality providing good NASA technical information. Noise is not objectionable.

Test 1 2 3 4 5      6 7 8 9 10      11 12 13 14 15

**MARGINAL** - The picture is poor in quality but contains significant NASA technical information. Noise is somewhat objectionable.

Test 1 2 3 4 5      6 7 8 9 10      11 12 13 14 15

**INFERIOR** - The picture is very poor but some NASA technical value remains. Objectionable noise is present.

Test 1 2 3 4 5      6 7 8 9 10      11 12 13 14 15

**UNUSABLE** - The picture is so bad that it is of no technical use.

Test 1 2 3 4 5      6 7 8 9 10      11 12 13 14 15

**CNR USED  
 FOR SURVEY**

6 10 0 4 12      2 8 12 6 14      0 8 2 10 4 DB

Adapted from Friendall and Behrend "Picture Quality - Procedures for Evaluating Subjective Effects of Interference", Proceedings of the IRE, June 1960.

CCIR Predistortion Visual Effect

CNR-DB	10	6	4	0
Improved Quality				
No Change				
Inferior Quality				

and operating procedures as the above quality survey were used. The compiled results of this survey, which involved 34 people, are given in Table 10-2. The deletion of emphasis from the system is certainly not confirmed by this survey. Above threshold (50 db weighted SNR) the survey confirmed that emphasis offers no advantages and was felt to be disadvantageous by 44% of the viewers. However, at 33 db weighted SNR and below, the majority opinion favored the use of emphasis. Based on these results, the recommended CAT Relay System will contain a crew selectable pre-emphasis network (Down FM Mode 2) in order to permit optimization of the TV downlink as a function of the link quality at the time of use.

CNR IN 20MHZ BW	10	6	4	0	DB
$(S+N)/N$ RMS/RMS	33.5	25.6	19.5	13.5	DB
$(S+N)/N$ WTD P-P/RMS	49.4	39.7	32.8	25.8	DB
EFFECT WITH EMPHASIS	ABOVE THRESHOLD	BELOW RECEIVER THRESHOLD			
IMPROVED QUALITY	9%	18%	53%	62%	% OF TOTAL OPINIONS PER LEVEL
NO QUALITY CHANGE	47%	47%	21%	29%	
INFERIOR QUALITY	44%	35%	26%	9%	
TOTAL OPINIONS	34	34	34	34	

54M  
12-16-68

Table 10-2. Results of Emphasis/No Emphasis Opinion Survey

## REFERENCES

- 10.1 Television/Audio Link Demonstration, NASA Communications and Tracking Relay Experiment, Motorola Report 3503-4, October 1968.
- 10.2 Frienddall and Behrend, "Picture Quality-Procedures for Evaluating Subjective Effects of Interference", Proceedings of the IRE, June 1960.
- 10.3 CCIR Recommendation 405, Geneva 1963.

## SECTION XI

### 11. PROGRAM SUMMARY

Motorola has designed a versatile Communications and Tracking Relay System with a variety of data relay expansion capabilities. This study program and the laboratory demonstration have proven that a Communication and Tracking Relay Experiment can be successfully implemented by employing existing equipment, most of which are space qualified. A long duration, good quality, commercial television link from the spacecraft to the ground and simultaneous high quality voice link are the unique features of the CAT Relay Experiment. The laboratory demonstration has solidified many operating parameters of the television relay system such as acceptable SNR, post-detection bandwidth, group delay distortion and voice channel quality.

#### 11.1 PERFORMANCE CAPABILITY

The television link will provide a 50.5 db SNR (weighted, p-p/rms) received picture at the ground for at least 50% of the possible ATS-R transmission time. Installation of a threshold extension demodulator at the ground station will provide a minimum 48 db picture for worst case link parameters. If unforeseen link degradation occurs during flight, the system will still provide technically useable video for at least 8 db of unforeseen link degradation. The voice link with the video will have greater than 50 db Spk/Nrms quality at the minimum picture goals stated above. This voice link will provide at least 70% intelligibility at 8 db unforeseen link degradation.

The CAT Relay System will provide capability for both ATS-R and USBE metric tracking. The equipment accuracy of the System is estimated to be 7.5 meters in range and 0.011 meters/second (at 1/sec sample rate) in range rate using either ranging system. Additionally, uplink voice and data and downlink crew voice and 51.2 kbps telemetry services are provided with at least 10 db margin over comparable Apollo CSM-USBE minimum requirements.

#### 11.2 EQUIPMENT VERSATILITY

The proposed design of the CAT Relay equipment on the AA Cluster can be readily upgraded to provide additional link margins. High power TWT's, larger antennas and lower noise figure preamplifiers can be added to the system at any reasonable time without major impact on the balance of the system.

The proposed CAT Relay design can also be readily upgraded to provide additional link services such as color downlink television, monochrome uplink television, emergency omni-antenna voice links, and additional combinations of USBE subcarriers and ranging. Direct AAC to ground television service is also possible if desired.

The recommended ground station implementation will allow variation in received bandwidths and baseband emphasis networks in order to provide experimental optimization of the downlink.

### 11.3 UNRESOLVED DESIGN AREAS

The total NASA program to provide a qualified, operational flight system and final ground station equipment can be obtained with a four phase program of which this CAT Relay Experiment Study program fulfills the initial Phase A/B. The program phases are as follows:

Phase A/B	Preliminary Analysis and Definition - Present Study
Phase C	Design
Phase D	Development/Operations
Phase E	Vehicle Integration Support

The major unresolved system design areas at the conclusion of Phase A/B are:

1. Design of a tumbling-attitude, omni-antenna coverage, voice link for emergency use without switching antennas.
2. Determination of existing ground station equipment in existence and what additional capability is needed to support the CAT Relay Experiment.
3. Determination of exact AAP vehicle equipment locations and all electrical, mechanical and thermal interface details.
4. Determination of EMI, environmental, fabrication and qualification test requirements for the flight and ground equipment.
5. Definition of a Steerable Antenna Subsystem specification and selection of an approved flight design.
6. Determination of the vehicle attitude accuracy performance so that antenna and Experiment antenna pointing accuracies can be defined.

The Phase C program is estimated to be six months long and is required to provide firm specifications and to tie down system details. The above

unresolved design areas will be completed in Phase C and system, unit and antenna subsystem specifications will be generated. Firm technical and cost proposals will be prepared for all units specified and a Steerable Antenna Subsystem subcontractor will be recommended. A preliminary antenna design will be performed and a prototype Baseband Processor unit will be designed.

An estimated twelve month Phase D program is required to fabricate prototype units, to integrate and test a complete prototype system and to produce and qualify the deliverable hardware.

A prototype Control and Monitor unit will be designed and fabricated and prequalification tests conducted on this and the prototype Baseband Processor units. This phase will also include fabrication of the remaining flight, qualification and ground equipment. Qualification tests will be conducted on each unit including the Antenna Subsystem and the Control and Monitor unit.

An estimated two month Phase E program will be required to provide system and antenna subsystem support for installation and equipment check-out aboard the flight vehicle.

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**APPENDIX A**

**MOTOROLA PHASED ARRAY  
GONIOMETER ANTENNA SUBSYSTEM**

In order to provide the full  $360^{\circ}$  axial scan coverage about the AA Cluster and to incorporate considerable flexibility into the antenna subsystem, Motorola has investigated the possible use of a phased array goniometer system. The goniometer is a beam-forming and scanning matrix for a circular array. Its major components include a lens to accurately phase the signals from the elements of the array, a diode switch matrix to properly connect the appropriate antenna elements and transmitter to the lens terminals, and a logic and driver circuit to control the diode switches such that the various beam scanning modes are accomplished. A circular antenna array operating in conjunction with the goniometer system allows  $360^{\circ}$  scanning at rapid electronic scan rates. The use of proper hybrid networks increases the versatility of the goniometer to include functions such as ten or more simultaneous multiple beams (including direct ground links), monopulse capabilities, and a variety of scan modes.

Motorola has developed goniometer systems under government contracts AF 30(602)-3960 and F 3060-67-C-0131. Figure A-1 shows a typical Motorola goniometer ground installation operating at a lower frequency and wider bandwidth than the subject satellite system.

Preliminary calculations were made based on a required 30 db gain at the subsystem input port to provide a communications link between the AAC and ATS-F for the CAT Relay Experiment. Assuming a 260 inch array diameter (Orbiting Workshop size), a related air dielectric goniometer lens must be one half that diameter. To increase the flexibility of installation of this lens, it will be dielectrically loaded with a low loss ( $\tan \delta < .002$ ) high dielectric constant ( $\epsilon_r = 25$ ) ceramic material to reduce its diameter to approximately one fifth the air dielectric lens diameter (2.16 feet). Figure A-2 shows a possible mounting position for the lens outboard of the AAC Airlock Module. A similar installation could be provided in the AAC Forward Skirt area. It is important to have the lens as close as possible to the antenna array to reduce cable loss and weight. Figure A-2 also shows a possible flush mounting configuration for the antenna array which would consist of approximately 4960 planar spiral elements. Each of these elements is estimated to be 2.6 inches square by one inch deep. Circular polarization is recommended to insure good reception at all aspect angles. The envisioned array would have 310 radiating groups (each consisting of 16 vertically stacked elements) around the circumference of the vehicle to give an azimuth beamwidth of approximately 1.2 degrees. An elevation beamwidth of about 6.5 degrees would result with a single r-f phasing control at each radiating group and could be increased with multiple phasing controls located at the group level. Each radiating group requires a separate r-f connection to the lens for proper beam steering.

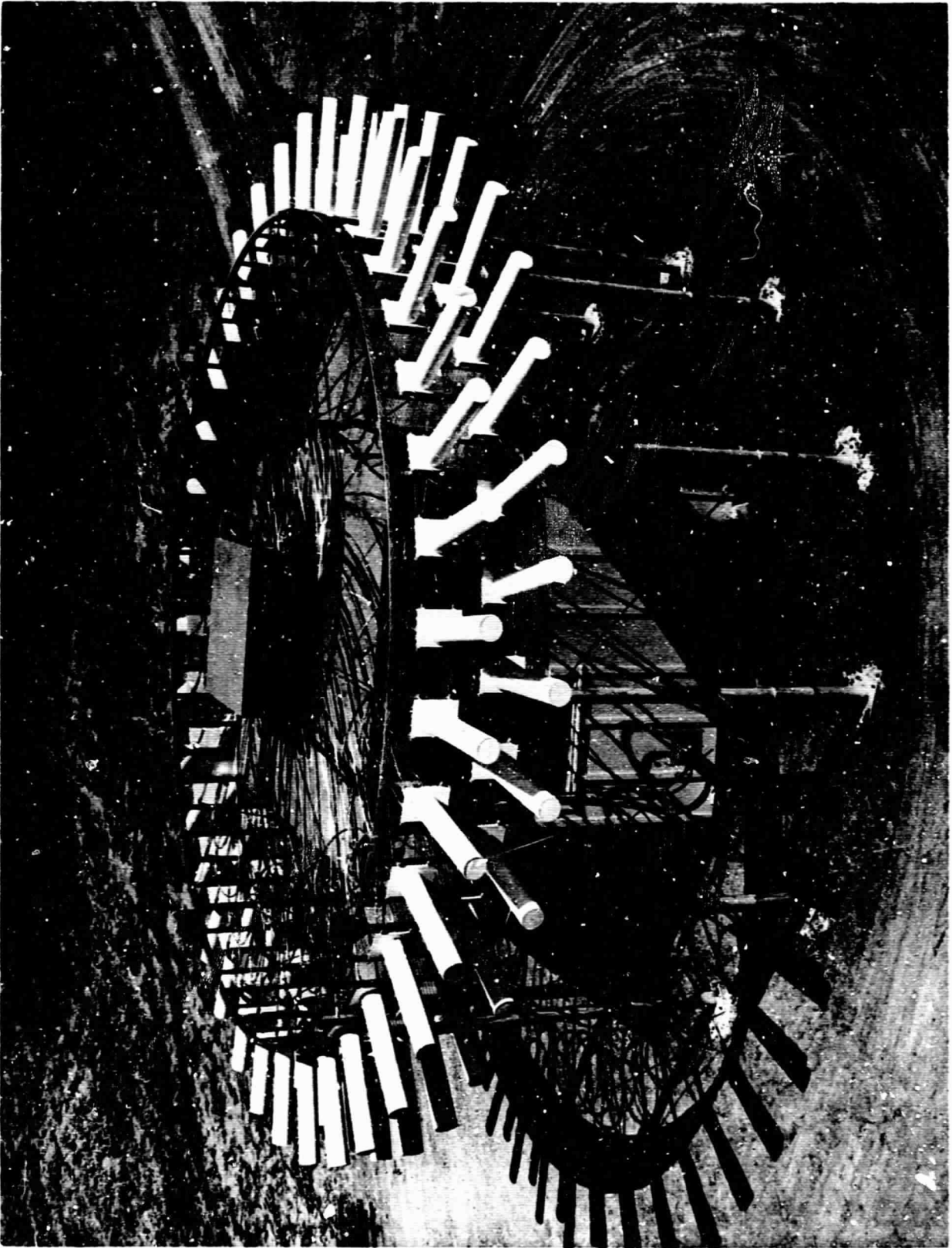
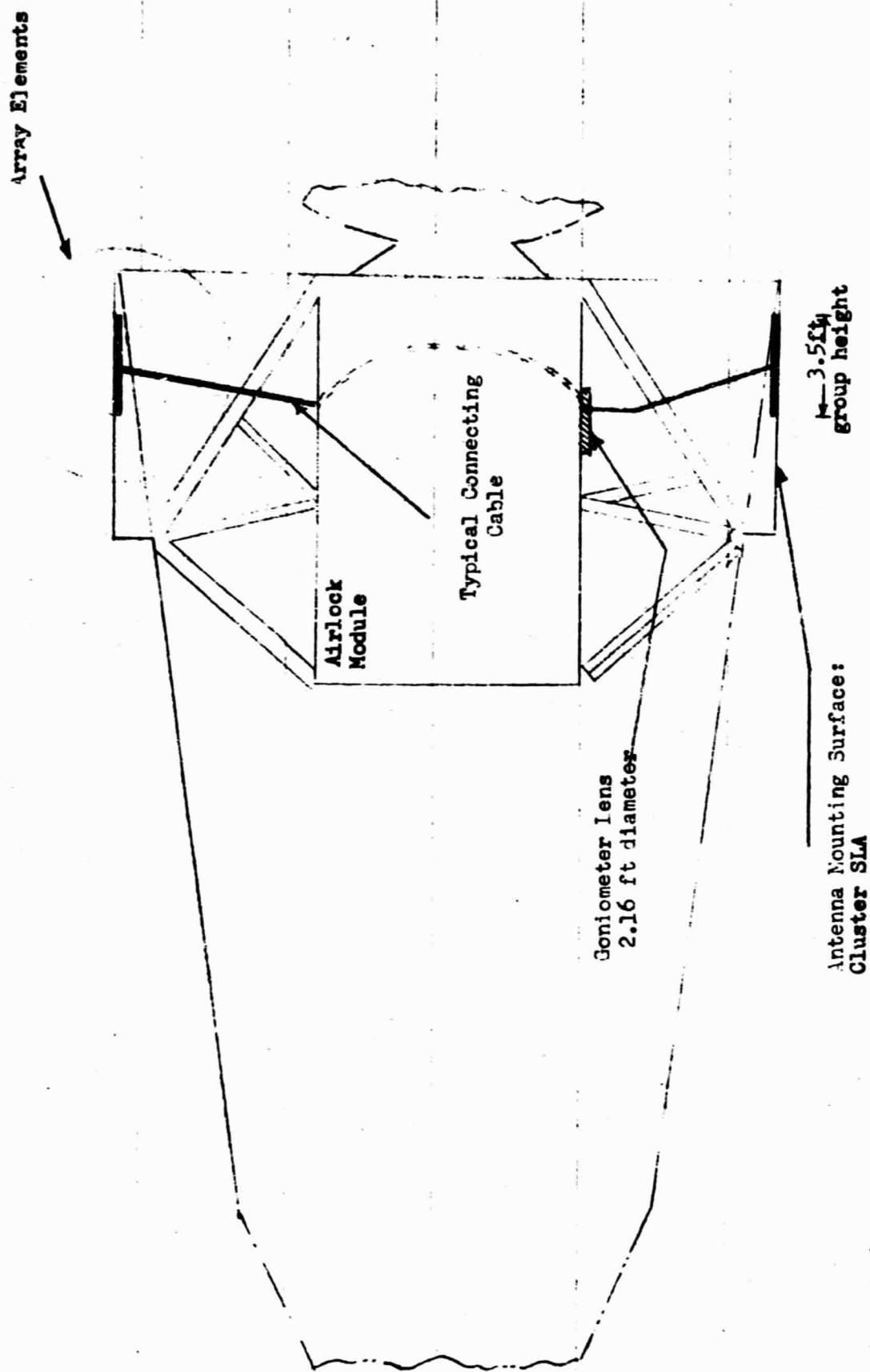


Figure A-1. Motorola Goniometer Antenna System for Ground Installation



**FIGURE A-2.** POSSIBLE ANTENNA SYSTEM MOUNTING CONFIGURATION

The array radiation patterns were determined based on an estimate of antenna subsystem losses. The losses include a 1.36 db loss in the lens, 3.84 db loss in the cable, 1.5 db diode switch loss, 0.3 db dielectric loss and an array efficiency of approximately 65%. With these losses included, the array gain will be a minimum of 30 db at 2253 MHz. In each case tradeoffs were made between size, weight and r-f loss. The lens loss was based on a TEM mode of radiation by the relationship:

$$\alpha \text{ lens} = \frac{27.3 \sqrt{\epsilon_r}}{\lambda} \tan \delta \text{ db per meter.}$$

The cable loss was based on the fact that the cables must wrap around the circumference of the Airlock or Forward Skirt void to reach elements on the opposite side of the vehicle. The dielectric losses include stripline transmission line to feed the elements contributing to the elevation patterns in each radiating group.

A total weight for the system including cables, the dielectric lens, printed circuit antennas, logic circuitry and miscellaneous is estimated to be 238 pounds. A possible installation concept would include a subframe mounting fixture which could be preassembled and tested and then installed wrap around style on the vehicle over the present superstructure.

The goniometer subsystem would switch power to the proper elements so as to provide constant illumination of the related ATS-F synchronous satellite. A 1 to 2 db azimuth ripple is expected to result from this goniometer antenna subsystem. This can be reduced by increasing the azimuth beamwidth and decreasing the elevation beamwidth, however additional elevation beam phasing and switching would be required. A method of acquiring another synchronous satellite prior to leaving the field of view of the one being illuminated could be easily implemented in the system. This would provide a smooth transition with no loss in link communications.

In order to achieve the desired 30 db gain, a 6.5° elevation beamwidth design restriction was arbitrarily imposed. As recorded in Section 2 of the text, a need for a 10° elevation beamwidth capability exists. As mentioned above, the subsystem can be adapted to provide 2 or 3 positions of discrete beam scan in elevation to insure the required 10° coverage. Switching diodes would be used in a stripline configuration to perform this scanning.

Motorola would be glad to provide additional details if required on this goniometer approach to an antenna subsystem for the CAT Relay System or any other likely application.